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PROJECT ADMINISTRATION DATA SHEET

Project No. B-551

DATE: 5/19/81

Project Director: B. William Riall, Jr.

~~School~~/Lab EDL/ARD

Sponsor: U. S. Department of Energy, Savannah River Operations Office

Type Agreement: Contract No. DE-AS09-81CS84090

Award Period: From 5/11/81 To ~~5/10/82~~ ~~11/5/82~~ 1/5/83 (Performance) ~~5/10/82~~ 11/5/82 (Reports)

Sponsor Amount: $55,000

Contracted through: ~~GTRI~~/GIT

Cost Sharing: N/A

Title: An Environmental Assessment of Increased Biomass Derived Energy Use in the Southeastern United States.

ADMINISTRATIVE DATA

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1) Sponsor Technical Contact: Mr. Raymond Costello, USDOE, Biomass Energy Systems Program, 600 E Street, NW, Rm 413, Washington, DC 20585

2) Sponsor Admin./Contractual Contact: Pat Crawley or Barbara Brightheart, Contracts & Procurement Branch, Contracts & Services Division, DOE, Savannah River Operations Office, P. O. Box A, Aiken, South Carolina 29801 PH(803) 725-2191/1169

Reports: See Deliverable Schedule

Security Classification: N/A

Defense Priority Rating: N/A

RESTRICTIONS

See Attached Government Supplemental Information Sheet for Additional Requiremen

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Date 9/18/84

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Project Director(s) B. William Riall, Jr. XXXX / GIT

Sponsor U. S. Department of Energy, Savannah River Operations Office

Title An Environmental Assessment of Increased Biomass Derived Energy Use in the Southeastern United States

Effective Completion Date: 1/5/83 (Performance) 1/5/83 (Reports)

Grant/Contract Closeout Actions Remaining:

- [ ] None
- [x] Final Invoice or Final Fiscal Report
- [ ] Closing Documents
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- [x] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other

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TECHNICAL STATUS REPORT

February 10, 1982

ENVIRONMENTAL ASSESSMENT OF INCREASED BIOMASS DERIVED

ENERGY USE IN THE SOUTHEASTERN UNITED STATES

CONTRACT: DE-A509-81CS84090

Following the receipt of the report done on biomass technologies for the northeastern U.S. it has been possible to continue our own research efforts. It should be noted, however, that we have not received the report covering the entire U.S. Though this report would benefit our efforts it is not possible for us to further delay action due to internal staffing considerations. The delays caused by the unavailability of these reports has been incorporated into a revised project management plan previously submitted which requests a no-cost time extension be formally incorporated into our contract equal to the time between when the northeast report was to be sent to us and when it was actually received.

The northeast report has now been reviewed and, as of this date, Task I of the project schedule is approximately 50% complete with a first draft scheduled for completion on February 23. It is now anticipated that the requirements of Task I and Task II will be incorporated into a single chapter due to the level of duplication which would exist if two separate presentations were produced. The completion of the first draft of Task I will enable preliminary work on Task III to begin at the end of February.

B-551

Technical Status Report

March 10, 1982

Environmental Assessment of Increased

Biomass Derived Energy Use in

The Southeastern United States

Contract: DE-A509-81CS 8490

EDL Project #B-551

The first draft of the description of technologies feasible for application in the Southeast has been completed. The framework for preparing the penetration scenario for those technologies is now being developed.

Technical Status Report

June 1982

Environmental Assessment of Increased

Biomass Derived Energy Use in

The Southeastern United States

Contract: DE-A509-81C 8490

EDL Project #B-551

Data collection efforts for the market penetration analyses is continuing. Preliminary indication are that signficant gaps exist in the data base. Alternatives to those data are now being investigated.

Technical Status Report

April 10, 1982

Environmental Assessment of Increased

Biomass Derived Energy Use in

The Southeastern United States

Contract: DE-A509-81C 8490

EDL Project #B-551

Revisions to the first draft of the description of technologies feasible for application in the Southeast have been initiated and are expected to be completed on April 21, 1982. The penetration scenario development for those technologies has been slightly delayed due to illness of the principal investigator for this task. The penetration scenarios are expected to be completed by May 15, 1982.

B 551

TECHNICAL STATUS REPORT

MAY 10, 1982

ENVIRONMENTAL ASSESSMENT OF INCREASED

BIOMASS DERIVED ENERGY USE IN

THE SOUTHEASTERN UNITED STATES

CONTRACT: DE-A509-81CS 8490

EDL PROJECT #B-551

The final draft of the technologies discussion has been completed. The penetration of these technologies (Task III) is progressing but is a larger task than was anticipated in the original proposal. The reason for this is that large data gaps are being discovered which can only be filled by adding new dimensions to the scenario analysis originally specified.

The general approach to be taken incorporates a standard logistic penetration formulation based, in this case, on perceived costs. The market to be penetrated is defined as all projected new equipment plus equipment requiring replacement.

The scenarios now anticipated to be investigated include:

1. Conventional fuel real price escalation rates of 0, 2, 4, 6, 8, and 10%

2. Biomass feedstock real price escalation rates of the same percentages

3. Real discount rate alternatives of 4, 6, 8, 10, and 12%

4. Penetration rates:

    a. Constrained to feedstock availability

    b. Unconstrained availability, i.e., assumes biomass "farms" formed.

5. Cost perceptions distributions with 'tails' defined as:

    a. .001% at a cost ratio of 1.95
    .999% at a cost ratio of .05

    b. .001% at a cost ratio of 1.80
    .999% at a cost ratio of .20

Both scenarios to assume unbiased perceptions at a relative cost of 1.00.

6. Penetration levels to be based on alternative scenarios of industrial growth of 0, 3, and 6% growth rates.

The analysis is to be carried out on a state-by-state basis and down to two-digit industry SIC codes for the years 1982 through 2006 in two-year increments. The year 2006 was chosen as an end point because it represents a 30-year projection from the latest year for which sufficient data are available for all needed parameters.

The alternative scenarios will be combined to provide a final high, medium and low penetration rate for biomass technology. From these penetrations, feedstock quantities demanded can be estimated and an environmental impact assessed.

Technical Status Report

July 10, 1982

Environmental Assessment of Increased

Biomass Derived Energy Use in

The Southeastern United States

Contract: DE-A509-81C 8490

EDL Project #B-551

The penetration analysis has temporarily been halted pending receipt of ORNL data which could provide considerable insight into how future analytical steps should be structured as well as providing data to implement our modeling efforts.

Technical Status Report

August 6, 1982

Environmental Assessment of Increased Biomass Derived Energy Use in The Southeastern United States

Contract: DE-A509-81C 8490

EDL Project #B-551

The analysis of the penetration of biomass technologies is proceeding and some initial conclusions have been reached. Our cost analysis was compared to that available from a very recent (4/82) ORNL study which overlapped to a certain extent. The data compiled by ORNL were more comprehensive in describing the cost structure of conventional and biomass technologies but less comprehensive in their presentation of scenarios. The overall conclusion to be drawn from both analyses, however, is that for potentially large industrial users of biomass technologies, the economics behind the choice of fuel is very sensitive to initial fuel cost and assumed fuel escalation rates. At current and projected fuel prices, biomass technologies are not particularly attractive unless shipping costs are virtually zero. In other words, biomass is expected to continue to be used mostly by those industries which use wood in their production process or, by those industries located very near such industries which have excess residues. These industries, however, can be expected to increase their utilization of biomass. Similarly, residential use of biomass can be expected to increase based on favorable economics, but because of the inconvenience factors, biomass is expected to remain a secondary heat source. The environmental impact of harvesting and collection will, therefore, be centered on the increased exploration of existing sources quantified to the maximum extent possible.

Technical Status Report

September 7, 1982

Environmental Assessment of Increased Biomass Derived Energy Use in The Southeastern United States

Contract: DE-A509-81C 8490

EDL Project #B-551

A subcontract with Dunwoody, Inc., has been negotiated and is expected to be executed in the near future. The purpose of the subcontract is to derive reasonable estimates of the supply of woody biomass in the southeast, given alternative price scenarios. This approach to biomass utilization was decided to be superior to estimates of individual biomass technologys' penetration due to the previously discussed problem of high variances.

The environmental impact analysis of this biomass utilization is concentrating on searching the literature for quantitative analyses of woody biomass harvesting as this appears to be the high impact area. Our research is focusing both on the primary impacts on nutrient depletion and erosion as well as secondary impacts on forest productivity. Other areas of research include the impacts in agriculture and, to a lesser degree because of its present and projected low utilization, aquaculture.

Technical Status Report

October 1982

Environmental Assessment of Increased

Biomass Derived Energy Use in

The Southeastern United States

Contract: DE-A509-81C 8490

EDL Project #B-551

First draft of the Environmental Impact chapter has been completed based on preliminary results of penetration analysis. These results were that the traditional biomass sources, i.e., forestry related, offered the greatest economically favorable utilization potential and would therefore receive the highest priority for quantification.

This portion of the environmental impact analysis concentrated on deriving the relevant parameters toward subsequent quantification of impacts. The goal was to compile the parameters available in the literature and to identify any gaps which exist. Unfortunately, many such gaps do exist which will limit the extent of quantification.

Technical Status Report

November 1982

Environmental Assessment of Increased

Biomass Derived Energy Use in

The Southeastern United States

Contract: DE-A509-81C 8490

EDL Project #B-551

The first data regarding the primary biomass sources have been received and a preliminary review has been made. More data are due to be submitted shortly. The data which have been received are now being compiled in a manner appropriate for the development of the biomass supply curves from which alternative energy price scenarios can be developed.

Technical Status Report

December 1982

Environmental Assessment of Increased

Biomass Derived Energy Use in

The Southeastern United States

Contract: DE-A509-81C 8490

EDL Project #B-551

The biomass supply curve estimations have been completed with very good statistical fits though insufficient data were available for fuel estimation of the supply curve for Kentucky. A simple technique provided a useful approximation for Kentucky. The development of biomass utilization scenarios based on alternative fuel prices and the subsequent quantification of environmental impacts is proceeding along parameters previously found to be available in the literature.

Annual Technical Report

May 1982

Environmental Assessment of Increased Biomass Derived Energy Use in The Southeastern United States

Contract: DE-A509-81C 8490

EDL Project #B-551

Tasks I and II dealing with the identification and description of biomass utilizing technologies economically and technically viable in the near-term for the Southeast has largely been completed. One additional area covered in these analyses was a brief investigation into the costs and availability of feedstocks for these technologies. Task III and Task IV dealing with market penetration of biomass utilization and the Environmental impacts of harvesting and collecting the feedstock necessary to fuel these technologies, respectively, have been addressed only cursorily at the present pending completion of the technology analysis. Upon technology analysis completion, the penetration analysis will proceed either along technology specific or feedstock specific depending on further analysis in this area. The environmental impact analysis can proceed only on the most general of terms until both the technology analysis and the penetration analysis have both been substantially completed.

A draft of the initial sections of the technology analysis is included here as Appendix A. A preliminary bibliography is also included. The initial data collection efforts conducted in preparation of the environmental impact analysis has resulted in a preliminary bibliography including both those documents received and those expected to be received in the forthcoming period. This bibliography is included as Appendix B.

APPENDIX A

DRAFT BIOMASS TECHNOLOGY ANALYSIS

AND

BIBLIOGRAPHY

Chapter I

BIOMASS ENERGY SYSTEMS TECHNOLOGIES IN THE SOUTHEASTERN UNITED STATES

INTRODUCTION

This chapter describes biomass conversion processes and systems which are, or could become, important in the Southeastern United States. The Southeast is defined by DOE Region IV and includes the states of Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee.

All forms of biomass process stored chemical energy formed during photosynthesis. Several pathways exist for the conversion of this stored energy into usable thermal energy for end use demands. Table 1.1 is a summary of the major categories of biomass conversion processes. The foremost current conversion process in terms of the number of applications and quantity of fuel consumed is direct combustion to produce thermal energy. Other processes involve the conversion of the biomass fuel into a more usable, convenient form. Some conversions produce a fuel suitable only for on-site usage such as biomass gasification and anaerobic digestion which yield a gaseous product. Others, such as liquefaction and pyrolysis yield liquids amenable to off-site utilization. Some technologies are not sensitive to the type of biomass fuel while others are. The following desriptions of each process will include information on suitable feedstocks. Additionally, the scale of each system, its level of process development, and potential applications will be addressed.

The purpose of this initial chapter is to screen all existing biomass energy systems for the applicability in the Southeast. Systems that do not appear feasible or those not near-term commercial have not been included. Many long range research projects comprise this group. Technologies passing this initial screening receive further inspection later in this report. Included in the description of each system is a final assessment of the feasibility of that technology in the Southeast.

An important aspect of each technology in determining its adoption is its efficiency. For the purposes of this report efficiency is defined as the ratio of the...

Table 1.1

Summary of Major Conversion Processes

Process	End Product	Application	Primary Feedstocks
Direct Combustion	Heat	Residential and Commercial Space Heating Industrial steam generation, space heating and direct drying	Stickwood, wood chips and forestry residue, agricultural residue
Pyrolysis	Char/Pyrolytic Oil	Production of transportable, alternate liquid fuel and activated charcoal or briquettes	Wood, agricultural residue, municipal waste
Liquefaction	Heavy Oil	Large scale production of liquid fuel from biomass	Wood
Gasification	Low Btu Gas	Substitute for natural gas in industrial boiler and drying operations	Wood, agricultural residue
Gasification/ Methanol Synthesis	Methanol	Alternate liquid fuel internal combustion engines, boilers and chemical feed stock	Wood
Fermentation	Ethanol	Alternate liquid fuel for internal combustion engines, boilers, and chemical feedstock	Natural sugars, grain, cellulosic material
Anaerobic Digestion	Methane	High grade substitute for natural gas	Manure

Adapted from: Energy From Biological Processes, Volume III, Office of Technology Assessment, U.S. Department of Energy, September 1980.

energy in the output products to the input energy. Efficiencies for each process, based on the latest available data, are included along with the process description. Another operational aspect presented for each system is the turndown ratio. Turndown ratio defines the part-load capability of a given process. For example, a turndown ratio of 2:1 implies the system can operate stably when the output is reduced by one-half. This ratio, therefore, provides a good measure of operational flexibility which is potentially an important aspect to the technology's marketability. In most circumstances high values of turndown ratio are preferred.

Recovery of the energy contained in biomass involves one of two paths, either direct combustion or conversion. Direct combustion recovers energy from the biomass in its solid form with little or no treatment while conversion transforms the solid biomass into a more convenient form. The primary conversion processes are liquefaction and gasification. Liquid or gaseous fuels are preferred because they can be utilized easier and more efficiently. The most feasible technologies are shown in Table 1.1. This table includes liquefaction, gasification, and direct combustion, and represents the most feasible near term technologies. Technologies screened out of this list are discussed in the succeeding paragraphs.

One process not considered was densification of the solid biomass into a more convenient solid form. The foremost solid state conversion process under scrutiny today is wood pelletization. The first U.S. patent for densification was issued in 1880. It describes a process where sawdust or other wood residues are heated and then compacted to approximately the density of coal by the action of a steam hammer. For a full century, however, no widespread use of a compact wood fuel has existed in the U. S. market. At present, there are several methods available for the densification of wood. Many of these are based on technology from the animal feed production industry. However, the application of this technology to a new material is not always straightforward. The use of wood fiber has created several problems which must be overcome for this technology to achieve its potential.

Of the technical problems associated with densification (especially pelletization), one of the most serious, yet probably the least understood, is that of die wear (McBowan, 1980). Die wear, as well as the horsepower required to force the feed material through the die, is a sensitive function of feed material moisture content. Die wear and horsepower increase significantly if the moisture content is too great. However, getting the material as dry as possible does not really solve the problem since die wear and horsepower requirements also increase significantly if the moisture content is too low. Moisture content below 10% is generally unacceptable as well as moisture content above 25%; for most operations, 15% to 20% is considered optimal. All current data relating to this problem is entirely empirical derived from trial and error operational experience.

Foreign material in the feedstock also adversely affects die wear. One of the most abrasive, yet common foreign materials in sawdust feedstock and other fine wood waste is silica. Extended storage periods can also be a problem with some densified wood fuels. Pellets wet from exposure readily disintegrate, thus covered storage is essential. Several industries using trial runs of pellets have reported significant fines generation. This phenomena is apparently due to breakup of the pellets during shipping and handling.

Despite the notable problems with densified fuels they do offer several advantages. The material is dried during the densification process which raises the heating value and yields higher boiler efficiency when combusted. The uniformity of the fuel simplifies handling and storage. Lastly, wood produces significantly less sulfur emissions than coal and many industries converting to wood have done so for environmental reasons. Pellets are attractive because they can be directly substituted for coal in most stoker systems as a result of their size uniformity.

Even with these important advantages biomass densification was not included as one of the feasible technologies for the Southeast due primarily to economic considerations. An analysis indicated that the production cost of densified biomass was over $35 per ton. This cost is higher than coal on a Btu basis. The cost coupled with the uncertainty of supply resulting from frequent equipment breakdowns and die replacement has caused customers and producers to lose interest in densified biomass. At latest report the only two pellet plants located in the Southeast had closed down and the outlook for future development was limited.

Another solid fuel conversion route, the Koppelman Process, was also eliminated from full consideration. This process removes oxygen from wood, leaving a product which is dry, densified fuel with 50% more heating value (per pound) than dry wood. This is a relatively expensive process requiring high temperatures and pressures and the resulting fuel value is no better than that of coal.

The next category of conversion processes considered was liquefaction. Several methods are available for the production of liquid fuels as presented in Table 1.1. Each procedure, except ethanol fermentation from agricultural feedstocks which was specifically excluded from this study, is considered feasible in the Southeast and receives further discussion in ensuing sections. In some cases there are sub-technologies within the broad group, such as entrained pyrolysis in the pyrolysis category, which received no elaboration because of their research nature and anticipated long period before significant market penetration. Liquefaction is favored as a conversion technique because it transforms solid feedstock into a more transportable, convenient liquid form which readily replaces petroleum fuels.

One liquefaction technique, i.e., extraction of oil from agricultural feedstock, was removed from consideration because of several disadvantages. Vegetable oil has been demonstrated to be an excellent diesel fuel but due to its limited availability can be used only in small quantities as an fuel extender. Since vegetable oil for fuel use would be competing with its food use for a scarce supply, both social and political questions could arise. A final drawback to vegetable oil utilization is its high cost per Btu.

The final group of conversion processes are concerned with producing a gaseous fuel. Several technologies are available for this type of conversion but only two, low Btu gasification and anaerobic digestion were considered feasible in the near term.

Other gasification processes which yield medium or high Btu gases are possible with biomass; however, system complexity and cost are higher, making implementation less likely. Oxygen blown gasifiers used for methanol synthesis (or to make other chemicals), are an exception and are dealt with in the section on methanol. Their use for conversion of solid biomass to fuel boilers, kilns, etc., is again unlikely in comparison to low Btu gas capabilities and economies. High Btu systems using biomass would be in competition with natural gas as well as coal based synthetic natural gas, limiting its potential for market penetration

1.1 Biomass Feedstock Characteristics Comparison

Before considering the processes suitable for biomass energy conversion, a brief discussion of available biomass feedstocks is warranted. While wood is the foremost feedstock in terms of current utilization and future potential for the Southeast, other alternatives do exist. In addition to the data for wood, information on animal wastes, selected crop residues and aquatic biomass specifically for energy is included. Table

1.2 summarizes pertinent properties for the various feedstocks. Information on availability, cost, moisture content, ash content, and heating value is shown.

Table 1.2

Feedstock Comparison

Feestock	Availability	Moisture Content (Wet basis)	Ash[1] Content	Higher Heating Value	Reference
Wood					
Processing Residue	Good	40-50%	1%	5000 Btu/lb.[2]	1
Harvesting Residue	Good	50-10%	1%	4500 Btu/lb.[2]	1
Whole Tree Chips	Good	50-60%	.5-1%	4500 Btu/lb.[2]	1
Animal Wastes					
Cow Manure	Limited	50-97%	13-14%	5750 Btu/lb. (dry)	2,4,5
Chicken Manure	Limited	72-80%	20-25%	5600 Btu/lb. (dry)	3,5
Crop Residues					
Bagasse	Local	43-47%	1-3%	8700 Btu/lb. (dry)	7,9
Rice Hulls	Local	9%	15%	-	6,8
Peanut Shells	Local	10-20%	2-4%	8500 Btu/lb.[2]	11
Cotton Stalks	Minimal	50-60%	9%	6810 Btu/lb. (dry)	6
Cotton Gin Trash	Minimal	23%	16%	7060 Btu/lb. (dry)	6
Peach Pits	Minimal	22%	10%	7960 Btu/lb. (dry)	6
Corn Stalks	Limited	12%	6%	7850 Btu/lb. (dry)	6
Aquatic					
Kelp	Potentially Good	90%	45%	8100 Btu/lb. (dry)	4
Duckweed	Potentially Good	95%	15%	7000 Btu/lb. (dry)	4,10
Water Hyacinth	Potentially Good	95%	15%	-	10

1. Ash is given as percentage of dry weight
2. Value given as received

Data on availability is in relative instead of absolute terms. Availability of the feedstocks can range from limited to excellent. Moisture content is expressed on a wet basis, that is the ratio between the weight of water in the material to the weight of dry material plus the water:

$$\text{Moisture Content, \%} = 100 \times \frac{\text{weight of water}}{\text{weight of water + weight of dry material}}$$

Thus, 50% moisture content implies that a pound of biomass contains 1/2 pound of water and 1/2 pound of bone dry material.

The ash content for each material is expressed as a percentage of dry weight. The energy content of the feedstocks is given by the higher heating value. The heating value is expressed in either one of two ways. It can be given in the as received condition which includes the moisture, or it is given as the Btu per dry pound if the moisture has been removed. The ash content and heating value are both important properties from the standpoint of energy applications. Ash, the noncombustible inorganic fraction, should be as low as possible and heating value should be as high as possible in energy related applications to reduce the amount of feed and waste material handled.

From the data presented in Table 1.2, it is clear that wood is a practical feedstock for energy conversion processes. Wood has a reasonable cost, is readily available, and exhibits relatively good properties. One major difference between wood and conventional fuels is its high moisture content. This factor results in significant modifications to wood systems compared to conventional systems.

Animal wastes form a second class of biomass feedstocks. Manure can be utilized through direct combustion or as a substrate for methane production. The availability of manure is somewhat limited since it is mostly dispersed on the range. Wastes are available from cattle feedlots, dairies, and poultry and hog operations. The value of manure is determined by its application. Applications in addition to fuel include fertilizer and feed. When processing costs are considered the value of manure can range from as low as a negative \$1/ton when used as fertilizer to \$30/ton when used as a feed. The high moisture and ash content associated with manure are not readily applicable to direct combustion but are suited to anaerobic digestion since the feed is diluted to 5% solids.

Also listed in Table 1.2 are several crop residues. Agricultural crop residues can be a source of biomass energy, but they face severe restrictions such as seasonal availability, collection and transportation difficulty, and generally limited quantities. The value of residues can be difficult to assess. They are usually considered as waste unless an application has been found. Bagasse has been determined to be worth

$65/ton (dry) to sugar companies since it currently serves as their primarily boiler fuel and any lost supply would have to be replaced by oil or gas. Peanut shells and rice hulls also have an alternative use as a filler in animal feeds. Unless they are dried either in a plant process or in the field, agricultural residues have a high moisture content which makes them similar to wood in this respect. As demonstrated by the table, heating values on a dry basis vary by over 25% for different residues.

A final source of biomass is the aquatic weeds. In the past, these plants were considered to be a nuisance as they clogged waterways and killed marine life. Today they are being studied as an energy source to be utilized for methane generation by anaerobic digestion. The moisture content of this material is in the range of 90-95%. This means aquatic biomass is readily adaptable to anaerobic digestion which requires material with 5% solids but has limited use possibilities as boiler feedstocks.

This section has sought to summarize the biomass resources available in the Southeast. While not comprehensive with respect to every possible species, every major category of biomass material has been included. The suitability of these biomass resources as feedstocks for each biomass energy system will be discussed in the ensuing sections.

1.2 Direct Combustion of Biomass Fuels

The direct combustion of biomass fuel to produce thermal energy for space heating, drying, and steam production is an age old method of fuel utilization. Direct combustion has advanced through the years to encompass various techniques, applications, and feedstocks. The flexibility of direct combustion processes coupled with reasonable capital costs, wide feedstock availability, and attractive fuel cost savings potential means that it should continue to grow as an energy process. The choice of an appropriate direct combustion system is influenced primarily by fuel characteristics. Grate burning can be one of two types, thin bed or heaped pile combustion (Brown, 1979). Each of these methods is discussed in detail below. Important fuel properties which affect selection of combustion equipment are moisture content and particle size. The three methods of directly combusting biomass which predominate are pile burning, suspension burning, and fluidized bed combustion (O'Grady, 1980). A discussion of the most common method of pile burning, typically referred to as stickwood combustion, follows.

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APPENDIX B

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AN ASSESSMENT OF INCREASED BIOMASS DERIVED ENERGY USE IN THE SOUTHEASTERN UNITED STATES
Phase I: Harvesting and Collection

FINAL REPORT

Prepared for
The U.S. Department of Energy
Biomass Energy Systems Program
Under Contract DE-AS09-81

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INTRODUCTION AND EXECUTIVE SUMMARY

The objective of this research was to complete the first phase of an investigation into the environmental impacts associated with increased use of biomass-derived energy. This first phase was concerned with:

1. Analyzing biomass technologies for applicability in the Southeast and then presenting the characteristics of those revealed to be feasible;

2. Estimating the level of biomass utilization for three energy price scenarios.

3. Analyzing the environmental impacts associated with the harvesting and collection of the biomass and quantifying those impacts to the maximum extent possible given the estimated utilization scenarios. The quantification, where possible, was then used to discuss the level of significance the various impacts posed.

The second phase of the project is associated with analyzing the impacts of the various technologies as they are expected to be used.

The results indicate that there is potential for large amounts of biomass, particularly forestry biomass, to be available, and used, for the production of energy. The technologies identified as feasible in the near term are varied, but by far the greatest potential lies in either direct combustion technologies or some form of pyrolysis/gasification. The primary feedstocks for these technologies are dominated by forestry-related sources though some agricultural biomass is economical in specific situations. The forms of the biomass are most likely to primarily be either stickwood for home use or wood chips/pulverized wood for commercial/industrial use. Some small amount of anaerobic digestion for methane will undoubtedly be also present, but the absence of a preponderance of large feed lot operations diminishes its likely market penetration.

Technologies investigated as potentially feasible, but later shown not to be so for the Southeast, include wood pelletization, methanol production from biomass, aquaculture, and catalytic liquefaction.

The use of agricultural biomass for energy poses more serious potential negative impacts due to the much higher intensity use level of these lands. Countering this, however, is a smaller likelihood that the economics of energy usage would favor energy from this source in a way which would impose burdens on agricultural lands greater than already existing. It is even possible that the use of anaerobic digestion of manure could increase the use of digested sludge as a soil conditioner over what is now returned to the land.

Aquaculture does not, at this time, appear to provide a feasible source of biomass materials except in rare and isolated circumstances. The economics of aquaculture energy are such that the necessary investment would be worthwhile only if the aquaculture could be made to serve a dual purpose such as waste water treatment. The problems of this are quite large and, as yet, not satisfactorily resolved.

Many sources for this biomass were identified and quantified. Of these sources, some were found to be essentially benign ecologically while others present clear negative impacts. In the latter category, the prospect of the development and use of short rotation woody crops presents a threat to long-term forest productivity through the depletion of necessary nutrients. Supplementing this depletion through external application of nutrients analogous to that in agriculture has not been investigated sufficiently to determine whether or not long-term forest productivity could be sustained in this fashion. It can be said, however, that the negative impacts of increased erosion and nutrient and sediment depositions into streams commonly associated with modern agriculture would also apply to silvaculture.

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Chapter I

BIOMASS ENERGY SYSTEMS TECHNOLOGIES IN THE SOUTHEASTERN UNITED STATES

INTRODUCTION

This chapter describes biomass conversion processes and systems which are, or could become, important in the Southeastern United States. The Southeast is defined by DOE Region IV and includes the states of Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee.

All forms of biomass process stored chemical energy formed during photosynthesis. Several pathways exist for the conversion of this stored energy into usable thermal energy for end use demands. Table 1.1 is a summary of the major categories of biomass conversion processes. The foremost current conversion process in terms of the number of applications and quantity of fuel consumed is direct combustion to produce thermal energy. Other processes involve the conversion of the biomass fuel into a more usable, convenient form. Some conversions produce a fuel suitable only for on-site usage such as biomass gasification and anaerobic digestion which yield a gaseous product. Others, such as liquefaction and pyrolysis yield liquids amenable to off-site utilization. Some technologies are not sensitive to the type of biomass fuel while others are. The following desriptions of each process will include information on suitable feedstocks. Additionally, the scale of each system, its level of process development, and potential applications will be addressed.

The purpose of this initial chapter is to screen all existing biomass energy systems for the applicability in the Southeast. Systems that do not appear feasible or those not near-term commercial have not been included. Many long range research projects comprise this group. Technologies passing this initial screening receive further inspection later in this report. Included in the description of each system is a final assessment of the feasibility of that technology in the Southeast.

An important aspect of each technology in determining its adoption is its efficiency. For the purposes of this report efficiency is defined as the ratio of the

Table 1.1

Summary of Major Conversion Processes

Process	End Product	Application	Primary Feedstocks
Direct Combustion	Heat	Residential and Commercial Space Heating Industrial steam generation, space heating and direct drying	Stickwood, wood chips and forestry residue, agricultural residue
Pyrolysis	Char/Pyrolytic Oil	Production of transportable, alternate liquid fuel and activated charcoal or briquettes	Wood, agricultural residue, municipal waste
Liquefaction	Heavy Oil	Large scale production of liquid fuel from biomass	Wood
Gasification	Low Btu Gas	Substitute for natural gas in industrial boiler and drying operations	Wood, agricultural residue
Gasification/ Methanol Synthesis	Methanol	Alternate liquid fuel internal combustion engines, boilers and chemical feed stock	Wood
Fermentation	Ethanol	Alternate liquid fuel for internal combustion engines, boilers, and chemical feedstock	Natural sugars, grain, cellulosic material
Anaerobic Digestion	Methane	High grade substitute for natural gas	Manure

Adapted from: Energy From Biological Processes, Volume III, Office of Technology Assessment, U.S. Department of Energy, September 1980.

energy in the output products to the input energy. Efficiencies for each process, based on the latest available data, are included along with the process description. Another operational aspect presented for each system is the turndown ratio. Turndown ratio defines the part-load capability of a given process. For example, a turndown ratio of 2:1 implies the system can operate stably when the output is reduced by one-half. This ratio, therefore, provides a good measure of operational flexibility which is potentially an important aspect to the technology's marketability. In most circumstances high values of turndown ratio are preferred.

Recovery of the energy contained in biomass involves one of two paths, either direct combustion or conversion. Direct combustion recovers energy from the biomass in its solid form with little or no treatment while conversion transforms the solid biomass into a more convenient form. The primary conversion processes are liquefaction and gasification. Liquid or gaseous fuels are preferred because they can be utilized easier and more efficiently. The most feasible technologies are shown in Table 1.1. This table includes liquefaction, gasification, and direct combustion, and represents the most feasible near term technologies. Technologies screened out of this list are discussed in the succeeding paragraphs.

One process not considered was densification of the solid biomass into a more convenient solid form. The foremost solid state conversion process under scrutiny today is wood pelletization. The first U.S. patent for densification was issued in 1880. It describes a process where sawdust or other wood residues are heated and then compacted to approximately the density of coal by the action of a steam hammer. For a full century, however, no widespread use of a compact wood fuel has existed in the U. S. market. At present, there are several methods available for the densification of wood. Many of these are based on technology from the animal feed production industry. However, the application of this technology to a new material is not always straightforward. The use of wood fiber has created several problems which must be overcome for this technology to achieve its potential.

Of the technical problems associated with densification (especially pelletization), one of the most serious, yet probably the least understood, is that of die wear (McBowan, 1980). Die wear, as well as the horsepower required to force the feed material through the die, is a sensitive function of feed material moisture content. Die wear and horsepower increase significantly if the moisture content is too great. However, getting the material as dry as possible does not really solve the problem since die wear and horsepower requirements also increase significantly if the moisture content is too low. Moisture content below 10% is generally unacceptable as well as moisture content above 25%; for most operations, 15% to 20% is considered optimal. All current data relating to this problem is entirely empirical derived from trial and error operational experience.

Foreign material in the feedstock also adversely affects die wear. One of the most abrasive, yet common foreign materials in sawdust feedstock and other fine wood waste is silica. Extended storage periods can also be a problem with some densified wood fuels. Pellets wet from exposure readily disintegrate, thus covered storage is essential. Several industries using trial runs of pellets have reported significant fines generation. This phenomena is apparently due to breakup of the pellets during shipping and handling.

Despite the notable problems with densified fuels they do offer several advantages. The material is dried during the densification process which raises the heating value and yields higher boiler efficiency when combusted. The uniformity of the fuel simplifies handling and storage. Lastly, wood produces significantly less sulfur emissions than coal and many industries converting to wood have done so for environmental reasons. Pellets are attractive because they can be directly substituted for coal in most stoker systems as a result of their size uniformity.

Even with these important advantages biomass densification was not included as one of the feasible technologies for the Southeast due primarily to economic considerations. An analysis indicated that the production cost of densified biomass was over $35 per ton. This cost is higher than coal on a Btu basis. The cost coupled with the uncertainty of supply resulting from frequent equipment breakdowns and die replacement has caused customers and producers to lose interest in densified biomass. At latest report the only two pellet plants located in the Southeast had closed down and the outlook for future development was limited.

Another solid fuel conversion route, the Koppelman Process, was also eliminated from full consideration. This process removes oxygen from wood, leaving a product which is dry, densified fuel with 50% more heating value (per pound) than dry wood. This is a relatively expensive process requiring high temperatures and pressures and the resulting fuel value is no better than that of coal.

The next category of conversion processes considered was liquefaction. Several methods are available for the production of liquid fuels as presented in Table 1.1. Each procedure, except ethanol fermentation from agricultural feedstocks which was specifically excluded from this study, is considered feasible in the Southeast and receives further discussion in ensuing sections. In some cases there are sub-technologies within the broad group, such as entrained pyrolysis in the pyrolysis category, which received no elaboration because of their research nature and anticipated long period before significant market penetration. Liquefaction is favored as a conversion technique because it transforms solid feedstock into a more transportable, convenient liquid form which readily replaces petroleum fuels.

One liquefaction technique, i.e., extraction of oil from agricultural feedstock, was removed from consideration because of several disadvantages. Vegetable oil has been demonstrated to be an excellent diesel fuel but due to its limited availability can be used only in small quantities as an fuel extender. Since vegetable oil for fuel use would be competing with its food use for a scarce supply, both social and political questions could arise. A final drawback to vegetable oil utilization is its high cost per Btu.

The final group of conversion processes are concerned with producing a gaseous fuel. Several technologies are available for this type of conversion but only two, low Btu gasification and anaerobic digestion were considered feasible in the near term.

Other gasification processes which yield medium or high Btu gases are possible with biomass; however, system complexity and cost are higher, making implementation less likely. Oxygen blown gasifiers used for methanol synthesis (or to make other chemicals), are an exception and are dealt with in the section on methanol. Their use for conversion of solid biomass to fuel boilers, kilns, etc., is again unlikely in comparison to low Btu gas capabilities and economies. High Btu systems using biomass would be in competition with natural gas as well as coal based synthetic natural gas, limiting its potential for market penetration

1.1 Biomass Feedstock Characteristics Comparison

Before considering the processes suitable for biomass energy conversion, a brief discussion of available biomass feedstocks is warranted. While wood is the foremost feedstock in terms of current utilization and future potential for the Southeast, other alternatives do exist. In addition to the data for wood, information on animal wastes, selected crop residues and aquatic biomass specifically for energy is included. Table

1.2 summarizes pertinent properties for the various feedstocks. Information on availability, cost, moisture content, ash content, and heating value is shown.

Table 1.2

Feedstock Comparison

Feestock	Availability	Moisture Content (Wet basis)	Ash[1] Content	Higher Heating Value	Reference
Wood					
Processing Residue	Good	40-50%	1%	5000 Btu/lb.[2]	1
Harvesting Residue	Good	50-10%	1%	4500 Btu/lb.[2]	1
Whole Tree Chips	Good	50-60%	.5-1%	4500 Btu/lb.[2]	1
Animal Wastes					
Cow Manure	Limited	50-97%	13-14%	5750 Btu/lb. (dry)	2,4,5
Chicken Manure	Limited	72-80%	20-25%	5600 Btu/lb. (dry)	3,5
Crop Residues					
Bagasse	Local	43-47%	1-3%	8700 Btu/lb. (dry)	7,9
Rice Hulls	Local	9%	15%	-	6,8
Peanut Shells	Local	10-20%	2-4%	8500 Btu/lb.[2]	11
Cotton Stalks	Minimal	50-60%	9%	6810 Btu/lb. (dry)	6
Cotton Gin Trash	Minimal	23%	16%	7060 Btu/lb. (dry)	6
Peach Pits	Minimal	22%	10%	7960 Btu/lb. (dry)	6
Corn Stalks	Limited	12%	6%	7850 Btu/lb. (dry)	6
Aquatic					
Kelp	Potentially Good	90%	45%	8100 Btu/lb. (dry)	4
Duckweed	Potentially Good	95%	15%	7000 Btu/lb. (dry)	4,10
Water Hyacinth	Potentially Good	95%	15%	-	10

1. Ash is given as percentage of dry weight
2. Value given as received

Data on availability is in relative instead of absolute terms. Availability of the feedstocks can range from limited to excellent. Moisture content is expressed on a wet basis, that is the ratio between the weight of water in the material to the weight of dry material plus the water:

$$\text{Moisture Content, \%} = 100 \times \frac{\text{weight of water}}{\text{weight of water + weight of dry material}}$$

Thus, 50% moisture content implies that a pound of biomass contains 1/2 pound of water and 1/2 pound of bone dry material.

The ash content for each material is expressed as a percentage of dry weight. The energy content of the feedstocks is given by the higher heating value. The heating value is expressed in either one of two ways. It can be given in the as received condition which includes the moisture, or it is given as the Btu per dry pound if the moisture has been removed. The ash content and heating value are both important properties from the standpoint of energy applications. Ash, the noncombustible inorganic fraction, should be as low as possible and heating value should be as high as possible in energy related applications to reduce the amount of feed and waste material handled.

From the data presented in Table 1.2, it is clear that wood is a practical feedstock for energy conversion processes. Wood has a reasonable cost, is readily available, and exhibits relatively good properties. One major difference between wood and conventional fuels is its high moisture content. This factor results in significant modifications to wood systems compared to conventional systems.

Animal wastes form a second class of biomass feedstocks. Manure can be utilized through direct combustion or as a substrate for methane production. The availability of manure is somewhat limited since it is mostly dispersed on the range. Wastes are available from cattle feedlots, dairies, and poultry and hog operations. The value of manure is determined by its application. Applications in addition to fuel include fertilizer and feed. When processing costs are considered the value of manure can range from as low as a negative $1/ton when used as fertilizer to $30/ton when used as a feed. The high moisture and ash content associated with manure are not readily applicable to direct combustion but are suited to anaerobic digestion since the feed is diluted to 5% solids.

Also listed in Table 1.2 are several crop residues. Agricultural crop residues can be a source of biomass energy, but they face severe restrictions such as seasonal availability, collection and transportation difficulty, and generally limited quantities. The value of residues can be difficult to assess. They are usually considered as waste unless an application has been found. Bagasse has been determined to be worth

$65/ton (dry) to sugar companies since it currently serves as their primarily boiler fuel and any lost supply would have to be replaced by oil or gas. Peanut shells and rice hulls also have an alternative use as a filler in animal feeds. Unless they are dried either in a plant process or in the field, agricultural residues have a high moisture content which makes them similar to wood in this respect. As demonstrated by the table, heating values on a dry basis vary by over 25% for different residues.

A final source of biomass is the aquatic weeds. In the past, these plants were considered to be a nuisance as they clogged waterways and killed marine life. Today they are being studied as an energy source to be utilized for methane generation by anaerobic digestion. The moisture content of this material is in the range of 90-95%. This means aquatic biomass is readily adaptable to anaerobic digestion which requires material with 5% solids but has limited use possibilities as boiler feedstocks.

This section has sought to summarize the biomass resources available in the Southeast. While not comprehensive with respect to every possible species, every major category of biomass material has been included. The suitability of these biomass resources as feedstocks for each biomass energy system will be discussed in the ensuing sections.

1.2 Direct Combustion of Biomass Fuels

The direct combustion of biomass fuel to produce thermal energy for space heating, drying, and steam production is an age old method of fuel utilization. Direct combustion has advanced through the years to encompass various techniques, applications, and feedstocks. The flexibility of direct combustion processes coupled with reasonable capital costs, wide feedstock availability, and attractive fuel cost savings potential means that it should continue to grow as an energy process. The choice of an appropriate direct combustion system is influenced primarily by fuel characteristics. Grate burning can be one of two types, thin bed or heaped pile combustion (Brown, 1979). Each of these methods is discussed in detail below. Important fuel properties which affect selection of combustion equipment are moisture content and particle size. The three methods of directly combusting biomass which predominate are pile burning, suspension burning, and fluidized bed combustion (O'Grady, 1980). A discussion of the most common method of pile burning, typically referred to as stickwood combustion, follows.

1.2.1 Stickwood Combustion

Process Description

Price hikes in traditional fuels such as natural gas and fuel oil have resulted in many southeastern homeowners installing wood stoves. Much of this activity has been centered in rural areas where fuel supplies are readily available, but there has been scattered emergence in urban and suburban areas as well. Stickwood heaters compose the simplest class of heaped pile combustors. Cut-to-length logs are stacked in the stove combustion chamber and ignited. Stickwood is classified as a "heaped" pile combustion since individual logs are relatively large in diameter and they are stacked two or three deep. Combustion of stickwood is limited to residential and small commercial because of the difficulties associated with handling such large pieces. The three types of residential stickwood stoves in use today are:

- fireplaces or nonairtight stoves
- airtight stoves
- furnaces

The oldest and most inefficient method of stickwood combustion is with an unregulated supply of air such as in fireplaces and nonairtight franklin stoves. Nonairtight stoves were the standard residential heat source in the United States during the years preceding the 1900's. Alternate units utilizing cleaner, more convenient fuels, such as oil and gas rapidly replaced most woodstoves and fireplaces in all but aesthetic instances. Airtight stoves have achieved a high level of development in part due to increased demand and utilization and are currently serving an expanding segment of the population. Even with drawbacks such as low energy density, increased operator attention and inconvenient fuel, airtight wood stoves will probably continue to increase in number as conventional fuel costs rise.

Nonairtight systems are inherently inefficient due to the inability of controling the air-fuel ratio. More efficient wood combustion is offered by airtight stoves which permit close adjustment of air-fuel ratios (Shelton and Shapiro). Many airtight stoves offer other design features including firebrick lining to reduce combustion zone heat loss and interior baffles to increase the residence time of partially burned gases thereby enhancing oxidation. The final type of stickwood combustion system is the airtight furnace. These units are available with several different design features. Some stickwood furnaces are designed to be added to existing forced air heating systems, or to heat water for hydronic systems. Wood furnaces usually incorporate components not found on air tight stoves to improve combustion. These components can include thermostatically controlled combustion air dampers, flow patterns to preheat combustion air, and forced draft combustion (Wood Energy Research Corp., 1981).

Technical Information

Residential scale wood stoves range in output from 20,000 - 150,000 Btu/hr. The most common sizes for residential woodstoves are between 20,000 and 50,000 Btu/hr. Furnaces for commercial scale applications can have outputs in the range of up to 2,000,000 Btu/hr. The sizes for wood furnaces are generally larger than stoves. They usually range from 150,000 to 2,000,000 Btu/hr. with commercial units 500,000 Btu/hr. and above. However, small furnaces with outputs as low as 30,000 Btu/hr. are available.

Turndown ratios for wood stoves are highly variable depending on the type of stove, design features, and fuel moisture content. A conservative estimate for turndown ratio is 2:1. Greater turndowns might be achievable but not without adverse effect on operating parameters such as smoking and creosote formation. Wood furnaces have a turndown ratio of approximately 3:1.

Several laboratories have tested the operating efficiencies of wood stoves. The range of efficiency to be expected for a given combustion system based on test results from the Auburn Woodburning Laboratory is shown in Table 1.3 (Dyer et al, 1980). Stove efficiency is determined by two primary components - combustion efficiency and heat transfer. Airtight stoves and furnaces exhibit good combustion efficiency due to the close control of air fuel ratio. Fireplaces provide no control over air fuel ratio and consequently large amounts of warm room air go up with the draft, thus operating with considerable excess air. In addition to burning the fuel properly, wood stoves must also be able to effectively transfer the heat produced in order to be efficient. Radiant and circulating wood stoves transfer heat from the stove surface and from the stove pipe by convection and radiation while fireplaces transfer heat largely by radiation. Heat transfer for stoves can be increased by adding more stove pipe. However, this cools the exhaust gases and can result in increased condensation of combustion products on the flue inner wall.

Table 1.3

Efficiency Range For Wood Heating Unit

Appliance	Estimated Efficiency Range
Masonry Fireplace	-10% to +10%
Manufactured Fireplace w/ Circulation and Outside Combustion Air	10% to 30%
Fireplace Stove	20% to 40%
Radiant Stove	45% to 65%
Circulating Stove	40% to 55%
Furnace	40% to 60%

Source: Dyer, et al. (1980)

Stove manufacturers are continuing to improve the design and performance of residential systems, and there is a vast potential for future improvements. Some stove companies are already offering catalytic combustors which improve efficiency by reacting uncombusted components in the flue gas and safety by reducing the potential for creosote deposition in the flue. Other modifications may include using forced draft to better control combustion and utilizing thermal storage to level heating demand.

Economic Data

Important economic data includes initial cost of the equipment and operating and maintenance costs. The most inexpensive wood stoves are the non-airtight models which range in price from $75-$250. These are also the most inefficient systems. Greater efficiency can be achieved at a higher initial cost by selecting an airtight stove. Airtight stoves cost anywhere between $300-$800, depending on the size of unit and additional design features. In instances where no chimney exists, a prefabricated metal chimney must be purchased and installed. Cost of a metal flue is about $1.50/inch for material plus an additional $1.00/inch for installation. With lengths of 100 inches common, flues can cost $250-$300 to install.

Wood furnaces due to their increased size and complexity over conventional units generally cost more. A typical cost range for furnaces would be between $500 and $8,000. For commercial scale systems especially, there would be an additional charge for installation as a result of the electrical connections required on fans and blowers.

Operating and maintenance data for woodstoves are almost nonexistent. A number that represents a reasonable estimate is $50/year in maintenance costs for the average woodstove. This figure represents the cost of replacing stove pipe and cleaning the flue. Not included in this figure is the cost of labor to load the stove, start the fire, and empty the ash. For the case of residential systems, the labor is assumed to be free.

Chip feeding systems do not command the same appeal in commercial and residential situations as they do in industrial situations because of the greater cost consciousness and lower system utilizations. For residential systems especially, the abbreviated heating season in the southeast lends little appeal to automatic systems. This is in contrast to New England, which as a result of their longer heating season, has shown some attraction for automated wood chip systems in the 75,000 to 10 million Btu/hr. range encompassing the residential and commercial markets (Wood Energy Research Corp., 1981).

Feedstocks

Because of their design, wood stoves and furnaces accommodate cut-to-length stick wood and are not suited to any type of chipped material. Most users use both seasoned and green wood as fuel sources.

Compilation of 1972 residential wood fuel data placed the consumption at 0.1 x 10^{15} Btu/yr. (0.1 quads) (Cliff, 1973). Since that time consumption has increased dramatically. A recent study estimated residential consumption to have risen to .3 quads by 1976 and .65 quads by 1980 (Hammond, 1977). It has been estimated that 500,000 residential wood stoves have been sold in recent years (Hammond, 1977). This represents more than a doubling of residential systems since 1971. Estimates of wood stove applications show that 66.7% of the equipment is used for supplemental heating and cooking, and 17% for primary heating and cooking (Tillman Academic Press, 1978).

Residential wood stoves are not significant consumers of biomass in any form other than stickwood. While many wood stove owners do use small portions of their municipal waste, mostly in the form of rolled up newspapers and magazines, as a fuel source manufacturers do not recommend that bulk garbage be burned because corrosive compounds, deleterious to the stove and flue, could be evolved.

1.2.2 Wood Chips and Pulverized Wood

The handling difficulties associated with stickwood has limited this type fuel to small-scale applications where the labor required and other inconveniences are offset by the fuel savings. In industrial situations where large amounts of fuel input are necessary, more convenient forms of fuel are required. The preferred form of wood fuel in most industrial situations is chipped or hogged green wood.

Industrial wood chip boilers are well developed and in wide use as illustrated by Table 1.4 which lists the wood boilers in the Southeast by state (Johnson, et al, 1979). The high utilization factor and large fuel consumption of industrial units makes the increased convenience of automatic chip feeding systems universally favored over manual stickwood arrangements.

Table 1.4

Wood Fired Boilers

State	Number of Wood Boilers	Industrial Consumption 10^3 Mg/Year	Commercial Consumption 10^3 Mg/Year	Total
Alabama	96	791.1	0	791.1
Florida	99	1890.6	0	1890.6
Georgia	102	2073.8	0	2073.8
Kentucky	16	61.7	2.3	64.0
Mississippi	20	1164.8	3.5	1168.4
North Carolina	35	2372.3	0	2372.3
South Carolina	32	614.2	0	614.2
Tennessee	75	541.6	0	541.6
TOTALS:	475	9510.0	5.8	9515.8

Source: Control of Particulate Emissions from Wood-Fired Boiler, R. Boubel, 1978.

Though apt to "bridge" in handling systems, green wood chips can be moved efficiently in properly designed conveyors. Bridging is defined as the condition when the material being handled is no longer free-flowing. Wood fuel as a class exhibits poor flow characteristics, and special attention to handling is necessary. Despite the problems experienced with handling utilization of wood chips allows considerable automation of the feed system which reduces the associated labor cost.

A complete wood chip energy system begins with a storage silo or bin where fuel is held. From the holding chamber wood is conveyed to the combustion zone where it is fed in and burned. Industrial applications of the generated thermal energy include hot air drying, space heating, and steam generation. The three types of burners for direct combustion of chipped wood are grate burners, suspension burners, and fluidized beds. Each type is discussed in detail below.

1.2.2.1 Grate Burners

Process Description

Grate burners are found in a number of configurations - some of which are very specialized in their application. All include a static grate on which combustion takes place. A variety of feed mechanisms, air flow regimes and combustion chamber shapes and characteristics are seen in grate burners. The predominant configurations include heaped pile burners such as the dutch oven, thin pile burners and special application chambers such as the Cook furnace.

Technical Information

Grates serve to support green wood while it dries. Drying is accomplished either by firing in a refractory chamber or with combustion air preheated by flue gas. These two different methods of drying each define a class of grate burning.

In one class of grate burning referred to as heaped pile combustion wood chips enter a refractory chamber and are dried by heat reflected back from the surrounding walls. Steady loads and coarse, wet fuel provides the prime situation for a heaped pile burner. Pile burners deliver a steady heat output effectively but do not handle load changes well because of the "fly wheel" or inertia effect built into the pile and large refractory area. Additionally, piles tend to be thick in the middle and thin at the edges permitting air to by-pass the center and flow around the edge. This limits drying at the center. Rough chunky fuel is preferred over fines because space for air flow through the pile is greater (Johnson, et al., 1979).

The prototype chamber heaped pile design is the dutch oven (Figure 1.1). Fuel drying, evolution of volatiles, and combustion of carbon occurs in the primary chamber. Overfire air, introduced in a secondary chamber, promotes combustion of entrained and volatilized material.

In heaped pile combustion such as a dutch oven the fuel is usually gravity fed through a fuel chute onto the grates forming a conical pile. In the refractory lined primary chamber, high temperatures are generated which serve to dry out the fuel. Underfire air serves to partially burn the fuel and drive off the volatiles. Burning is completed in a secondary chamber where overfire air is injected. The major advantage of this design is its ability to utilize wet fuel of a rough, chunky consistency. A major disadvantage is that the fuel/air ratio changes as the fuel pile burns down, thus making control difficult. Turndown ratios are limited to around 3:1. The most serious drawback to the dutch oven is low efficiency (60% to 70%) caused by:

(1) increased heat loss due to the furnace's large surface area, and

(2) absence of radiant heating since the furnace and boiler are separate.

Gravity feeding of fuel onto the pile causes two emission problems:

(1) it increases the probability of unburned particles being entrained and leaving the combustion zone as particulates, and

(2) it causes some cooling of the combustion zone and hinders complete combustion.

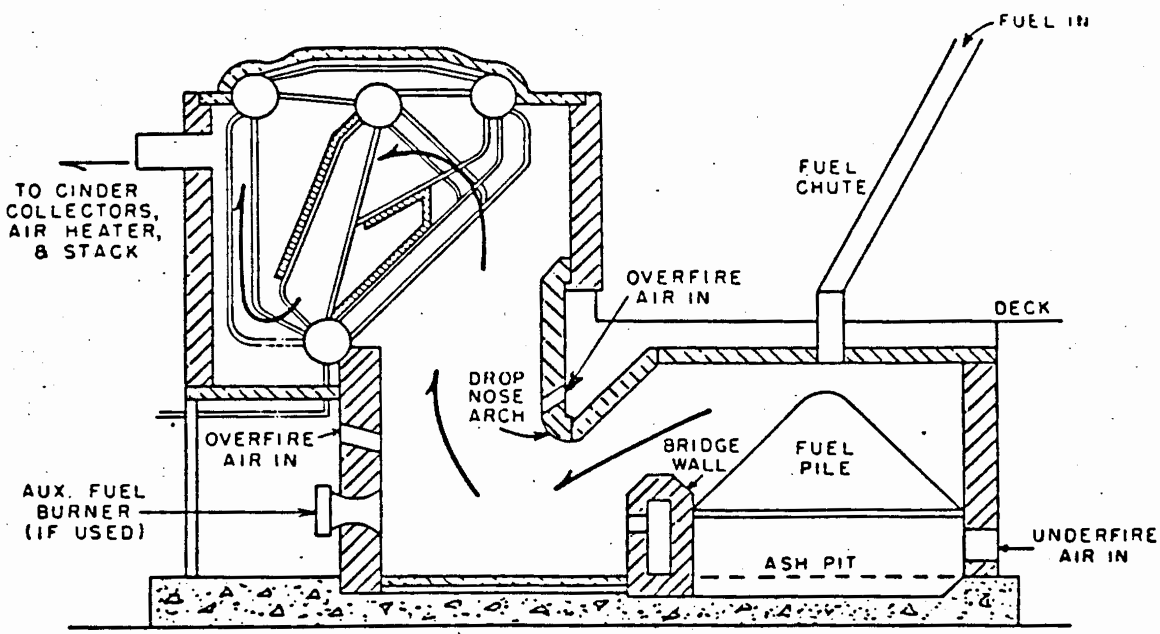
These problems can be effectively eliminated by pushing the fuel onto the pile from underneath. This is accomplished through the use of an underfed stoker.

Underfed stokers have been used with heaped pile designs. Control problems due to the thermal inertia of the fuel pile and refractory remain, but because cold fuel does not fall through the combustion zone, burning is improved and entrainment of small particles above the combustion zone is reduced.

In addition to the dutch oven heaped pile burner two other furnaces of similar design are the Dietrich and Wellons cell burners (Boubel, 1978). Both cells are

Figure 1.1

Dutch Oven Heaped Pile Burner



vertical, refractory lined chambers with fuel fed in from above. Refractory maintenance is expensive and time consuming, and control is difficult with rapidly varying steamloads (Johnson, et al., 1979). Like the dutch oven, turndown ratio is limited to 3:1.

Heaped pile burners are limited in output because of problems created with the proper mixing of volatile combustibles and difficulty in fuel drying when the fuel piles become too large. Standard dimensions for a dutch oven are 8 feet by 9 1/2 feet, but this may be varied somewhat to suit existing conditions (DeLorenzi, 1951).

This size is established by empirical factors such as the slope of the pile which is constant and the exhaust area required. Typical outputs for dutch ovens and cell burners are below 25,000 lb./hr. steam. The output of these systems can be increased by combining two or more ovens or cells into a battery. For example, a 60,000 lb./hr. boiler utilizing Wellon's cells as the heat source requires three cells.

In the other method of grate burning, the fuel is in thinly spread piles. Fuel is spread in this arrangement by gravity, pneumatic, or mechanical means. Because the pile is thinner more air can flow up through the grates than in the heaped pile case and the distribution is more uniform since air does not by-pass the bed around the edge. The undergrate air serves several purposes:

(1) Provides oxygen for combustion of fixed carbon;

(2) Cools the grates;

(3) Contributes to fuel drying.

In thin pile burners the fuel is burned in the base of a water-wall boiler unit as opposed to a refractory chamber. With the refractory removed, the fuel is dried by forced draft air that has been heated by the flue gas in an air pre-heater. Wet fuel (50% moisture) requires air heated to approximately 400° F in the preheater to guarantee stable combustion. Overfire combustion air is introduced above the grates to promote turbulence and complete the combustion of entrained and volatilized materials.

Figure 1.2 shows a typical thin pile burner. Fuel is injected with a spreader stoker. The combustion air is preheated by flue gas before entering the furnace. Radiant heat, captured by the furnace water walls, helps to improve system efficiency.

A typical thin pile grate burner would be a field erected boiler with sloping or traveling grates. Fuel slides into the furnace on the sloping grate or is injected in with a spreader stoker on a traveling grate. Particulate problems associated with dropping fuel in from above are eliminated with a sloping grate. The grate slope is a function of the fuel condition. Since dry fuel slips easier than wet fuel, the grate is designed with different slopes in the drying and combustion zones (MacCallum, 1979). The thin fuel pile allows more uniform air distribution as compared to heaped pile, burning, and combustion rates can be increased more rapidly. Wet fuel is still allowed, but more size uniformity is required to permit proper distribution by the fuel injection system. One problem with sloping grates is the difficulty of preventing blowholes in the fuel bed, especially with nonuniform fuel. Also, to date, sloping grate boilers have not been made in sizes as large as spreader stoker boilers. Sloping grates have proven to be extremely reliable and have low maintenance costs. Fuel is introduced through multiple chutes at the upper end of the grate.

The majority of large wood-fired boilers utilize spreader stokers for fuel induction coupled with traveling grates (Figure 1.2). Functions of the traveling grate include providing a floor on which the fuel can burn, conveying ashes out of the boiler, and providing a platform for drying the fuel. The stoker can be mechanical or pneumatic. Mechanical spreader stokers resemble a paddle wheel and "throw" fuel into the boiler while pneumatic spreader stokers use air pressure to "blow" fuel into the boiler. Pneumatic stokers find wider application with wood fuel due to the size inconsistency of wood. These boilers have high heat release rates due in part to the smaller fuel particles burning in suspension. Heavier particles fall to the grate where they are burned in a thin bed. Spreader stoker installations can burn wet fuel (55% moisture content) without a heavy refractory lined drying chamber because drying is achieved with preheated forced air (Johnson, 1979). High heat release rates, integration of the furnace and boiler, and lack of refractory all contribute to a smaller and lighter boiler.

Disadvantages of spreader stokers include:

(1) absence of refractory means that a brief fuel interruption could extinguish the flame;

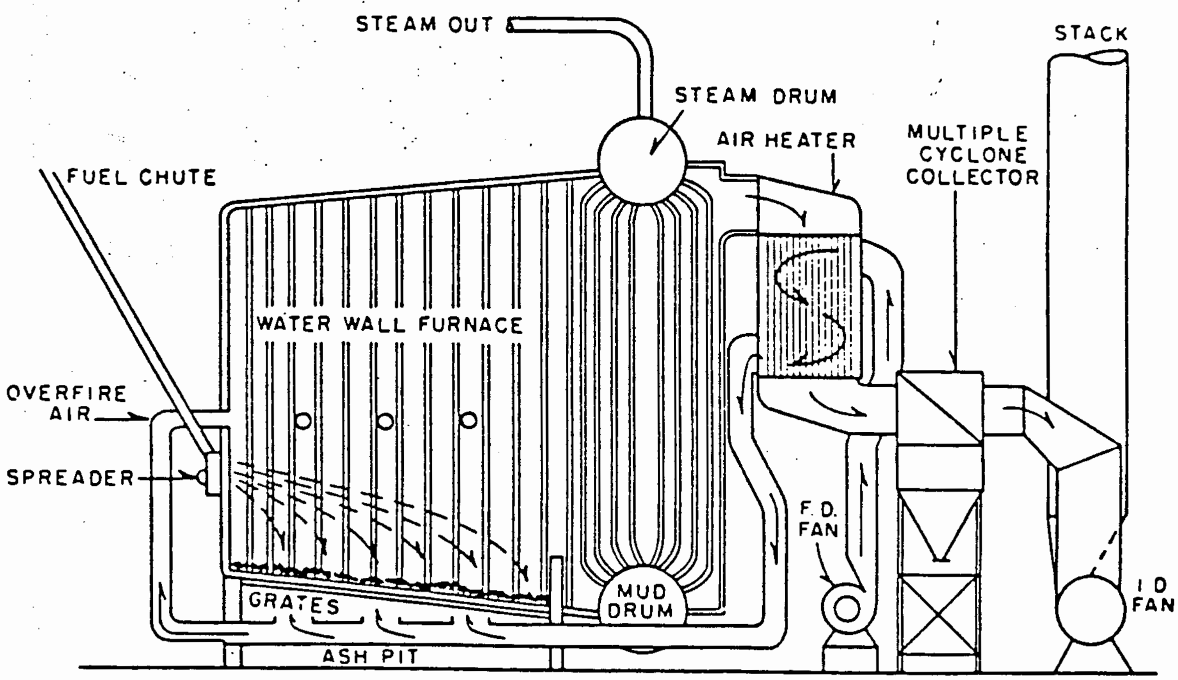
(2) overfeed fuel induction leads to heavier particulate loading;

(3) since traveling grates generally rotate back-to-front, heavier hogged fuel particles can fall straight down and be only partially burned when dumped;

(4) In general, traveling grates have high maintenance costs.

Figure 1.2

Thin Pile Wood Combustion



Thin beds are designed to allow air to pass through with relatively low undergrate pressures as the driving force. This encourages uniform excess air ratios above the grate improving combustion. For good operation, the fuel should be quite uniform in size; otherwise streaks or pockets of greater density than adjacent areas may lead to formation of blow holes in the bed (Boubel, 1978).

Thin pile burners are employed in boiler systems where larger outputs are necessary. Sloping grate systems range in size from 25,000 to 180,000 lb./hr. of steam. Traveling grate systems produce outputs as high as 400,000 lb./hr. Due to the increased maintenance associated with traveling grates, units below 100,000 lb./hr. are not practical. The efficiency range for thin bed combustion systems is typically between 65%-75%.

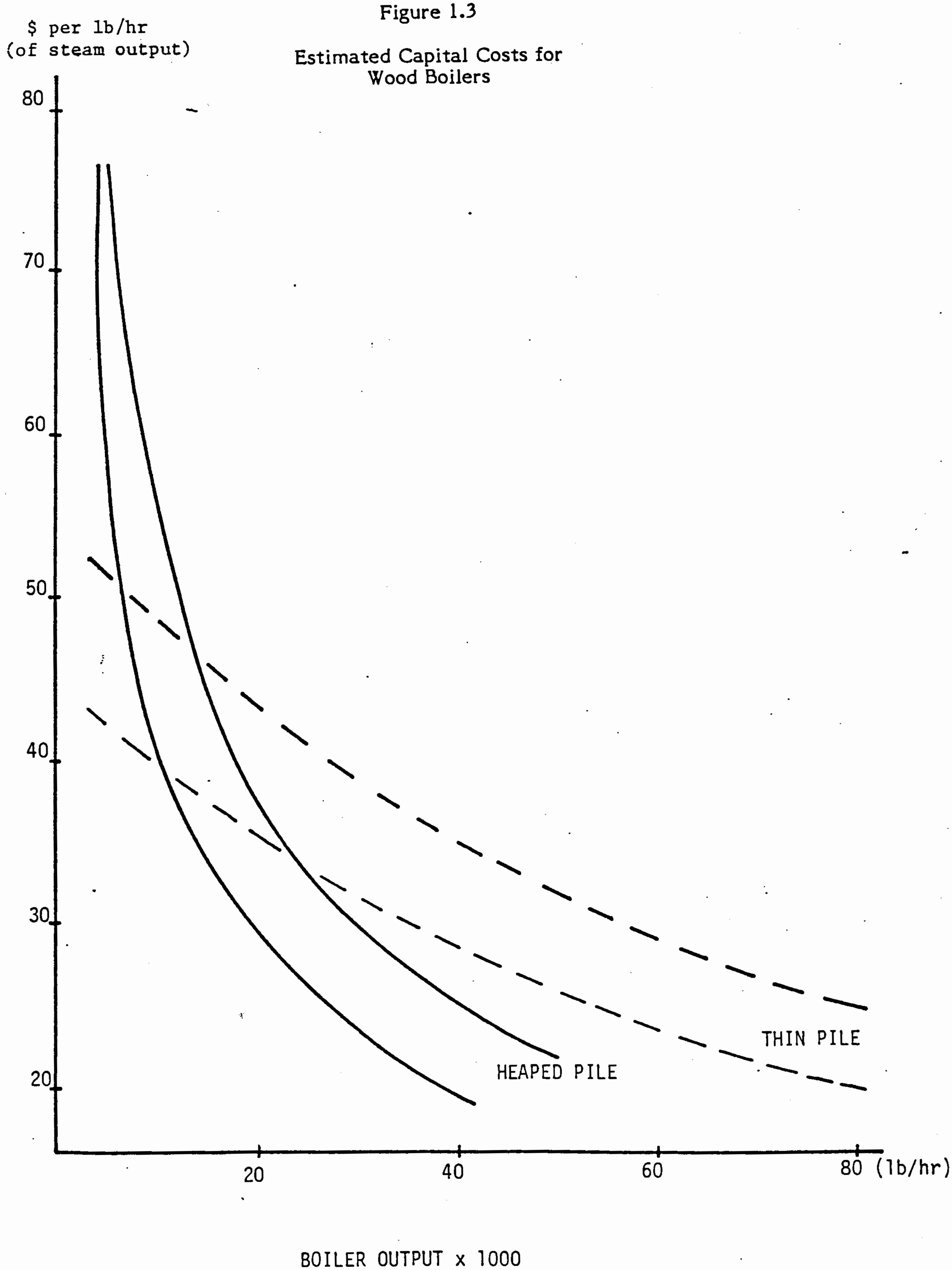
Economic Data

Although direct combustion equipment for wet biomass is divided into two major types, cost data for each of these types is similar. The parameter typically used to express the cost of steam systems is dollars per pound per hour of steam. This is the cost of the installed system per unit output with output represented in the pounds of steam produced an hour. The estimated cost for boilers from 5,000 lb./hr. to 80,000 lb/hr., both heaped and thin pile designs are shown on Figure 1.3. The graph illustrates that the economy of scale significantly influences boiler cost up to about 80,000 lb./hr. Above this size, increased boiler complexity begins to offset the economy of scale and unit cost stabilizes. The graph shows that unit capital costs for small boilers are very large because fuel handling, preparation, and storage equipment similar to that on large systems is necessary but the resulting steam production rate is small. Heaped pile boilers are not seen in sizes above approximately 35,000 lb./hr. as discussed previously while thin pile burners are employed above this output.

In addition to the economies of scale, many other factors such as the fuel characteristics, operating pressure, and automation also influence the cost of a steam generation unit. For the purposes of this report an average figure, $30 per pound per hour of output steam, has been used to arrive at capital costs. This number is an equitable compromise between the high unit costs of small output systems and the lower costs of larger ones.

Figure 1.3

Estimated Capital Costs for Wood Boilers



Soure: Various Contractor's Cost Data, 1980

The capital cost figure contains the typical ancillary equipment required for a steam generation system utilizing chipped biomass. This may include fuel unloading, handling, preparation and storage devices, pollution control, ash handling equipment, equipment enclosures, boiler controls and instruments, and installation in addition to the steam generator.

Figure 1.4 is a graph of boiler operating and maintenance costs. Curves for conventional gas boilers, wood chip boilers, and fluidized bed boilers are presented. Maintenance costs are 5% of the invested capital in each case, and the operating costs include labor and utilities. Operating costs are not, therefore, a fixed percentage of invested capital. As the figure illustrates, operating and maintenance costs, expressed in dollars per pound of output, increase expontentially as the size of the system decreases. This behavior is due primarily to the labor costs involved. Even the smallest biomass systems require full-time labor which inflates the operating and maintenance costs. Utility costs, however, tend to increase linearly with size. The figure indicates that operating and maintenance costs for biomass boilers are over three times greater than those for gas boilers. This is attributable to the greater labor, utility, and higher maintenance associated with biomass systems.

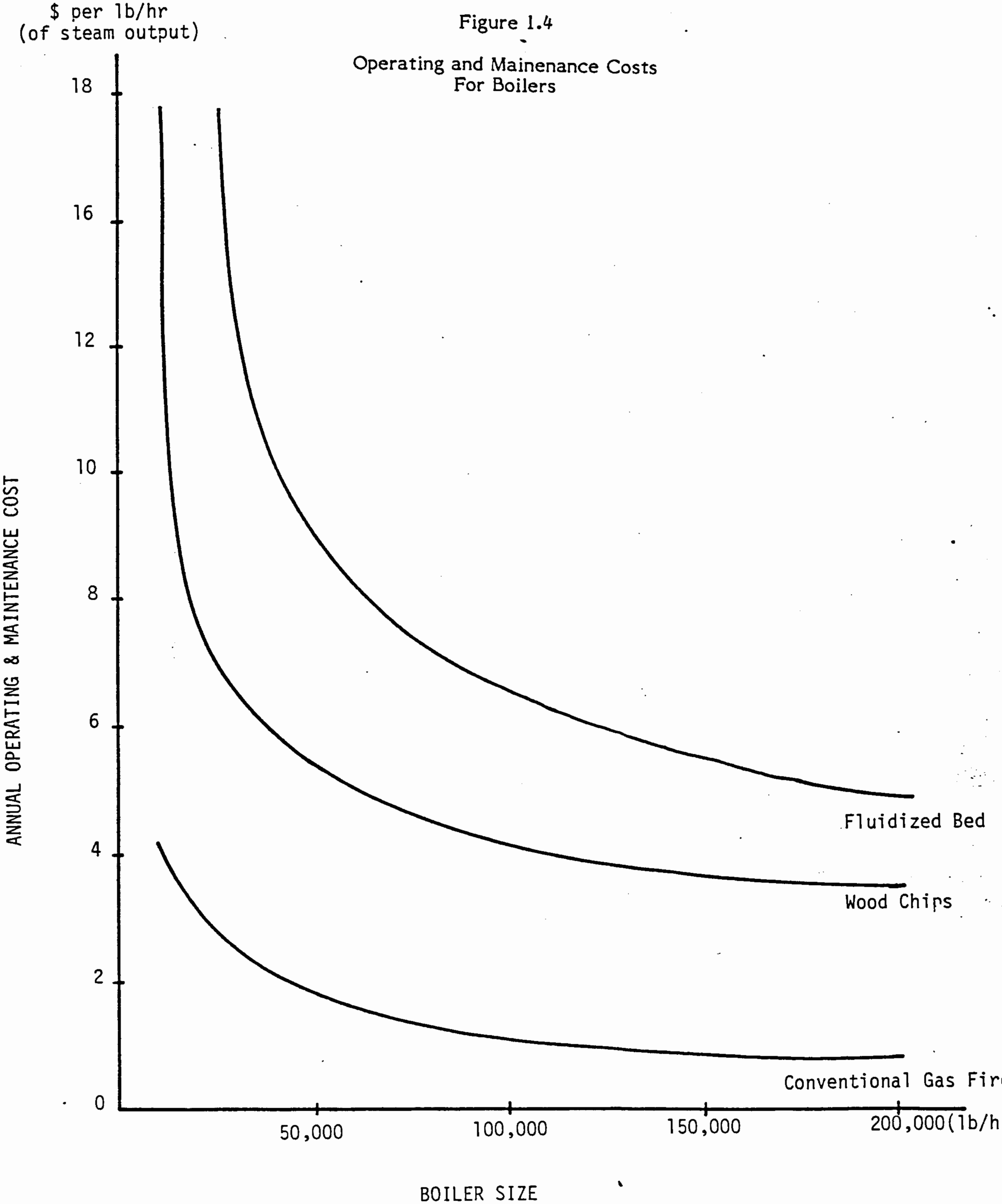
Feedstocks

In addition to wood chips, other biomass fuels can be used. A common feedstock in certain parts of the southeast is agricultural waste. Bagasse (which is the refuse remaining after juice is extracted from sugar cane) is the typical boiler fuel on sugar plantations in South Florida, for example.

Combustion of bagasse requires a different furnace than that used with wood. A Cook furnace is typically employed (Levelton & Assoc., 1978). It is horseshoe shaped with air tuyeres located around the curvature of the wall. The horseshoe shape was adopted to make it easier to distribute fuel over the entire hearth area and to eliminate corners which are difficult to clean. A refractory hearth is preferred over flat grates because of the slagging nature of the fuel. The ash from bagasse contains a high percentage of silica which together with silt or soil carried in with the cane will form glass-like clinkers if allowed to accumulate. The physical properties of bagasse are moisture content 41-45% fixed carbon 43-47%, heating value per dry pound of

Figure 1.4

Operating and Mainenance Costs
For Boilers



Adopted from: Central Heating Fossil-Fired Boilers, C.F. Blazek, et al, ANL/CES/TE79-4, Argonne National Laboratory, 1979

8000-8700 Btu, and ash 1.3-3.0% (Combustion Engineering Power Systems, 1979). These properties closely approximate those of green wood.

Several other types of agricultural residue are also being used as fuel. Agricultural wastes employed as fuel include nut shells such as from peanut and pecans, rice hulls, corn cobs, cotton gin waste, and others. Agricultural wastes typically contain high levels of noncombustibles usually in the form of soil. The high ash content coupled with the low heating value translate into greater fuel consumption and increased ash disposal problems.

Even with these disadvantages, agricultural residue can make sense in the right situation. Seasonal availability and transportation difficulties inhibit large-scale crop residue applications, however, many agriculture operations can justify residue utilization. Residue combustion can become essentially a free source of fuel for seasonal drying and processing demands in addition to a convenient waste disposal technique.

Because of their energy density, collection and transportation of residues can become major expenses. Therefore, the residues generally utilized are not those left out in the field but the ones brought in and discarded during or after the process. Included in this group is bagasse, cotton gin trash, corn cobs, and nut shells. Experiments to study the use of these materials are ongoing. Another factor influencing the use of residues is the magnitude of the competing uses. Bagasse, for example, can be pelletized for cattle feed, pressed into wall board, or used as furfural feedstock (Tillman Academic Press, 1978).

1.2.2.2 Suspension Burners

Process Description

In addition to pile burners for wood chips the two other direct combustion methods, suspension and fluidized bed burning, are gaining acceptance in industrial applications. Suspension burners are restricted to low moisture (below 15% wet basis) and small particle size (1/4"-1/2" maximum dimension) fuel. The fuel is injected into a turbulent air stream where it is suspended until combusted (Drucker, 1981). Suspension burners were designed to utilize dry, pulverized fuel such as sanderdust but can also use larger particle fuel that is dried and pulverized. Suspension burners produce energy in the form of hot gases and are used on dryers, kilns, and package boilers. These burners are commercially available and many industrial installations are operating. Units range in output from 5-60 million Btu/hr (Levelton & Assoc., 1978).

Technical Information

Several design variations of suspension burners are available. The oldest design, which has been in service since 1964, is the Coen dual-air-zone burner. Combustion air is admitted through louvers to form two counter rotating air streams (core and annulus). The air streams provide turbulent mixing action at the point of fuel induction. Another major type of burner was designed by Energex, Ltd. The Energex unit is a single-chamber cyclonic burner. Air is admitted tangentially to the refractory inner lining from a combustion air manifold to generate the cyclonic action. Other suspension burners are variations on these fundamental designs.

Although they are somewhat limited in application due to the requirement for dry fuel, suspension burners enjoy widespread application in the lumber and furniture industry where they are mostly used with dryers. Because these units fire dry fuel they yield high heat release rates and temperatures (over 2000^{o}F). Suspension burners have turndown ratios in the range of 4-5:1.

Due to the high temperatures generated in suspension burners, combustion is promoted helping to burn the fixed carbon and volatiles completely. Because there is no heat transfer between the combustion gases and another medium efficiencies of over 95% are expected with losses due mostly to heat transfer from the outer surface.

Economic Data

The estimated cost for a 15 million Btu/hr. output suspension burner is $300,000 complete (Hammond, 1977). This includes the burners, controls, installation and fuel preparation equipment. A dryer has been excluded. Because a large system would require the same components, its cost would not be markedly greater. Suspension burner systems do require a secondary fuel such as gas or oil for start-up.

Based on manufacturer's supplied data, operating and maintenance costs for suspension burners have been calculated. They estimate the major maintenance item to be the high temperature refractory lining which costs approximately $2,000 and lasts 1-2 years.

The systems are automatic so little labor is involved except for daily check-ups. A 15,000,000 Btu/hr. system will have 38 kw (51 hp) of connected electrical horsepower. Auxiliary fuel is required for start-up and the annual cost of the fuel will be dependent on the frequency of starts. Table 1.5 shows how the unit operating cost was calculated and the parameters included. For suspension burners an annual operating cost of $1240/MMBtu was determined.

Feedstocks

Feedstock is limited to dry, processed wood waste. Most agricultural residue is not acceptable because of its high moisture content.

An acceptable moisture content for suspension burners is typically less than 15%. Fuel must be sized to less than 1/4 inch.

Table 1.5

Suspension Burner
Operating and Maintenance Costs

Output	=	15,000,000 Btu/hr.	
Operation	=	8,500 hr./yr.	
Labor	=	$10/hr.	
Electricity	=	$.04/kw-hr.	
Maintenance	=	$2,000/yr.	
Labor	=	$3,560/yr.	(1 hr./day x x 356 da/yr x x $10/hr.)
Electricity	=	$12,920/yr.	(8,500 hr./yr. x $.04/kw-hr. x 38 kw)
Auxiliary Fuel	=	$100/yr.	
	=	$18,580/yr.	

Unit Cost = $\frac{18,580}{15}$ = $1240/million Btu/hr.

1.2.2.3 Fluidized Bed Burners

Process Description

Direct combustion of biomass in fluidized bed combustors is a relatively new technology which is receiving wide attention. In fluidized bed combustors a bed of hot inert material, usually sand, is fluidized from underneath by fans to provide a turbulent mixing zone for combustion (Levelton & Assoc., 1978). Fuel is generally dropped into the bed from above. The turbulent mixing action of the hot bed material helps ensure complete combustion of the fuel. Wet biomass fuel can be accommodated by a fluid bed as can fuel of irregular shape. Fluidized bed combustors are available in output ranges from 5-120 million Btu/hr. Fluidized bed combustion is a proven technology with many units operating in industrial environments. Applications include steam generation and hot air supply to rotary dryers. Current emphasis for this technology is coal firing with limestone added to the bed for sulfur cleanup, however, they receive considerable attention with biomass fuels due to their ability to accomodate wet, course material.

Technical Information

Fluidized bed units produce hot gas in the 1700-2000°F range. These gases can be used in drying operations or to produce steam in convective boilers. One fluid bed system attempts to improve efficiency by incorporating a water cooled combustion chamber to preheat boiler feed water. Turndown ratios for these units average 3:1. Advantages include the wide variation in fuel moisture contents and sizes accepted and good combustion efficiency. Among the disadvantages of fluidized beds are higher capital and maintenance costs than conventional boilers, and the high power requirements of the fluidizing fans.

Combustion efficiency is affected by fuel moisture content. A fluidized bed unit can achieve an efficiency of 75% with 50% moisture content fuel. Lower moisture fuel will yield higher efficiencies.

Unlike combustion systems requiring uniform size fuel, fluidized beds will accept oversize slabs and ends. The turbulent action of the granular bed continually grinds away the ash on the surface exposing fresh material for combustion. While large pieces of fuel can be accepted, manufacturers recommend hogging input to less than 3 inches. With fuel this size, the control system is capable of modulating the output better.

The depth of the bed between different units varies from 15 to 24 inches. Fluid bed systems require auxiliary fuel to preheat the bed to approximately 900°F when starting cold. Connected electrical horsepower to a system varies with the bed depth and boiler pressure. A typical 20 million Btu/hr. system would have an electrical load of about 149 kw (200 hp.)

Economic Data

Installation of most fluid beds is performed on a turn-key basis. A small unit of 10 million Btu/hr., including fuel storage and all necessary ducting, costs about $500,000 (Hammond, 1977). Costs vary depending on the specific application. The units are typically automated and do not require a full-time operator.

Operating and maintenance costs for fluidized bed systems were included on Figure 1.4 along with other boiler systems. Fluidized bed per-unit-of-output operating and maintenance costs behave like those of other boilers increasing with decreasing size. Figure 1.4 also demonstrates that fluidized bed costs are significantly greater than conventional wood chip or natural gas boilers. These costs can be attributed primarily to the higher utility costs associated with fluidized beds.

Feedstocks

Because fluid beds are able to tolerate high moisture contents a wide variety of fuels have been used. Systems have operated on olive pits, peach pits, and tomato seeds and skins, but the most common biomass feedstock is wood. The maximum fuel moisture content tolerated by fluidized beds is typically 65%.

1.3 Pyrolysis/Liquefaction of Biomass

Synthetic oil can be produced from biomass feedstocks through two technologies (Tillman Academic Press, 1978). Pyrolysis is a thermochemical conversion process which yields three products: pyrolytic oil, charcoal, and off-gas. The other method produces synthetic oil from wood "flour" slurry through a catalytic process.

1.3.1 Pyrolysis

Process Description

The thermal decomposition of wood, in the absence of sufficient oxygen for complete combustion, leads to the formation of a combustible gas, liquid products, and charcoal. Such processes are commonly referred to as gasification, pyrolysis, and carbonization, respectively. For the purposes of this study, the processes of thermal decomposition which emphasize combustible gas are referred to as gasification (to be discussed in a succeeding section). All other processes, emphasizing the production of liquids and solids are referred to as pyrolysis. It should be understood that there is no basic difference between gasification and pyrolysis as physical/chemical processes, and that the terminology is adopted purely for convenience to distinguish between the major outputs.

Technical Information

An energy balance on the dry feed input of pyrolysis shows that char and oil each account for 35% of the total output energy, off-gas 22%, and losses the remaining 8%. Several variations of pyrolysis processes exist. Each is designed to maximize the production of a different product. Synthetic oil produced by pyrolysis can be burned as fuel oil or upgraded into chemical feedstocks. Char can be utilized to produce activated carbon or charcoal briquettes. The flexibility of the output products is one major advantage of pyrolysis systems.

Another appealing aspect of pyrolysis is the form of the output. Pyrolysis yields a liquid fuel, i.e.,pyrolytic oil, which is a more convenient and transportable form than solid biomass. Pyrolytic oil has a heating vlue of 10-13,000 Btu/gal. with a viscosity dependent on the moisture content. Nominal viscosity is about 1/10 that of No. 6 fuel oil but tends to increase with prolonged heating due to polymerization. The distribution of product yields - char, oil and gas - varies somewhat with feedstock and is also controlled by the operating parameters, primarily the air-to-feed ratio. Operation at a low temperature with a low air-to-feed ratio yields a high volatile char and corresponding lower yields of oil and gas. Operation at higher temperatures yields a low volatile char and increased amounts of oil and gas. The volatile content of chars ranges from a low of 3% to a high of 50% (Knight, 1980). Low volatile char is useful for producing activated charcoal whereas high volatile char is desirable for manufacturing briquettes. The heating value of char ranges from about 11,000 to 13,500 Btu/lb. While the wide variety of pyrolysis products is an advantage, demonstrating the flexibility of the process, it can also be a disadvantage in some cases. Because of limited application data the uses for pyrolytic oil are restricted, and the installation of a pyrolysis system demands the identification of a market for charcoal.

Contact with pyrolysis manufacturers revealed a range of outputs from 10-200 million Btu/hr. available. Pyrolysis has shown high conversion efficiencies. The data report earlier, which had losses of 8%, corresponds to a conversion efficiency of 92%. Efficiencies between different systems may vary somewhat, but they are all expected to lie between 85-95%. There is no turndown ratio as such associated with a pyrolysis system since they are designed to produce a constant output product; however, the production of gas can be doubled by operating the system as a gasifier and not condensing oil. Note that in this case the energy throughputs do not change but only the form of the output changes.

The units developed thus far have been of fixed bed design but at least one firm is offering a fluidized bed reactor and research on entrained bed pyrolysis is also underway. To be economically attractive, pyrolysis systems must usually be quite large. While manufacturers contend that pyrolysis systems are ready for commercial operation, most are in the pilot stage and thus the technology must be considered precommercial.

Economic Data

Manufacturers were contacted for cost data on pyrolysis systems. Due to the complexity of pyrolysis systems considerable variations in price existed. Typical areas that tend to increase the cost are feedstock dryers, oil cleaning and filtering, char and oil storage, and feedstock handling. The data indicated the pyrolysis systems would cost from $20,000 to $40,000 per million Btu of output. The variation is due to site specific factors in addition to the particular design options selected.

Table 1.6 summarizes the owning and operating costs for a 40,000,000 Btu/hr. pyrolysis system. Annual Maintenance costs were determined to be approximately 6% of invested capital. The only external utility required is electricity. A 40,000,000 Btu/hr. unit is expected to have 150 hp (112kw) connected. The manufacturer indicated that the proposed system would require two people full-time to operate it. One man would be responsible for controlling the unit while the other would watch over the feedstock and product handling equipment. Summing these individual factors yields a figure of $223,860/yr. or $5,600/million Btu/hr. for the maintenance and operation of a pyrolysis system.

Table 1.6

Operating and Maintenance
Costs for Pyrolysis System

Output	=	40,000,000 Btu/hr.	
Operation	=	7,000 hr./yr.	
Labor	=	$10/hr.	
Electricity	=	$.04/kw-hr.	
Maintenance	=	$ 52,500	(6% of Invested Capital, 0.6x875,000)
Electricity	=	31,360	(112 kw x 7000 hr. x $.04/kw-hr.)
Labor and Supervision	=	140,000	(7000 hr. x 2 x $10/hr.)
Total		$ 223,860/yr.	

$$\frac{223,860}{40} = \$5,600/\text{mmBtu}$$

Feedstock

As pointed out earlier, pyrolysis sysetms were originally developed as a method of solid waste disposal. Pyrolysis does not actually dispose of the waste but convert it to a more desirable form. Feedstocks with moisture contents of less than 5% are required. This requirement appears to be a serious restriction for pyrolysis systems, but most of the current systems utilize off-gases for fuel drying. Thus an application for the off-gas, which must be used on-site, is defined and a wider variety of feedstock is accommodated. One perceived advantage of the pyrolysis process is the wide feedstock possibilities. Already wood and agricultural residues are used, and tests with municipal solid waste have been conducted.

1.3.2 Catalytic Liquefaction

Process Description

Another method of producing synthetic oil from biomass is the catalytic hydrogenation process originally developed by the U.S. Bureau of Mines. Solid biomass materials are liquified by heating to about 660°F (350°C) under carbon monoxide and steam pressure in the presence of sodium carbonate, water, and recycled oil. The feed material is a slurry of wood or biomass "flour" and recycled oil (Davis et al., 1981). The synthetic oil produced has a heating value of 9-13,000 Btu/lb. Suitable feedstocks include all solid biomass materials such as wood, newsprint, refuse and manure. Presently the minimum plant size for commercial operation is considered to be 1000 tons per day. The current state of development for this technology is a 3 ton per day pilot unit.

The catalytic liquefaction process is technically feasible, but many parameters must be fixed before a commercial plant can be designed. The large size of a commercial plant will require a guaranteed feedstock supply. Disadvantages of the liquefaction process include the high degree of feedstock processing required and the uncertain properties of the synthetic oil produced. Since liquefaction is still in the pilot stage of development, actual operating data is limited.

Technical Information

The first step in the catalytic hydrogenation process begins with part of the incoming feed being pyrolyzed to synthesis gas. Carbon monoxide (CO) in the synthesis gas and steam are reacted with the balance of the feedstock which has been finely ground in the presence of an alkaline carbonate catalyst at elevated temperature (700°F) and pressure (1500-3500 Psig). This converts the wood fractions to oil products. The process efficiency, defined as the ratio of the energy in the product to the energy in the feedstock, is in the range of 60-65% for catalytic liquefaction. The plant efficiency, defined as the ratio of the energy in the product to the total plant energy input, is between 33 and 38%.

Economic Data

Since the catalytic liquefaction process is still in the development stage, estimation of investment costs are difficult. A preliminary investigation revealed that a facility to process 1,000 dry tons per day would cost approximately $60,000,000 (McGowan, 1980). The high cost is the result of the complexity of the process.

A plant processing 1000 tons/day could produce about 24,400,000 gallons per year of oil. Operating costs for this plant include maintenance, labor, and utilities. Maintenance is assumed to be 5% of invested capital annually. Operating costs are summarized in Table 1.7.

Feedstocks

The catalytic liquefaction process thus far has utilized only wood as a feedstock. The most extensive research has been on Douglas Fir. Test have shown that high lignin content feedstocks have lower conversion efficiencies and lower product yields (Milam). Though it has not been demonstrated, other biomass materials that can be gasified can also be liquified.

Table 1.7

Operating and Maintenance Costs for Catalytic Liquefaction Process

Output	= 24,400,000 gal./yr.	
Capital Investment	= $60,000,000	
Maintenance	= $3,000,000/yr.	(5% of Invested Capital, .05 x 60,000,000)
Labor Costs	= $3,200,000/yr.	
Utilities	= $250,000/yr.	

$$\text{Unit Cost} = \frac{\$6,450,000}{488 \text{ million Btu/hr.}} = \$13,200/\text{million Btu/hr.}$$

Source: Economic and Technical Design Manual for Wood Systems, T.F. McGowan

Properties for the oil produced by catalytic liquefaction are different than those for #6 Fuel Oil as shown in Table 1.8.

Table 1.8

Properties of Oil Produced
by Catalytic Hydrogenation

	Catalytic Oil	#6 Fuel Oil
Energy Value Btu/lb.	15,000	18,200
Density lb./gal.	8.58	8.18
Elemental Analysis		
C	77.0	85.7
H	10.7	10.5
N	2.8	2.0
O	8.8	2.0
S	0.3	0.7-3.5

Adapted from: Wood as an Energy Resource, D. Tillman, 1978

Catalytic oil is acidic and difficult to handle. One advantageous property of the catalytic oil is the low sulfur content it possesses when compared to #6 fuel oil. The catalytic process favors material high in hemicellulose. Material high in lignin, like Douglas fir bark, consumes more CO during processing, has lower conversion efficiency, and less product yield.

1.4 Gasification

Process Description

The thermal decomposition of wood in the absence of stoichiometric oxygen for complete combustion results in the formation of a combustible gas. The purpose of gasification is to convert solid fuel to a more convenient gaseous state. As discussed previously, the process of biomass gasification is not unlike pyrolysis. In gasification, however, the production of a burnable gas is favored over oil and char. Typically, gasification processes yield a gas in which carbon monoxide and hydrogen are the principal combustible components with only minor amounts of high hydrocarbons present. Air blown gasifiers produce a gas with a heating value of 100-150 Btu/ft.^{3} (McGowan, 1982). The low heat content results from the large fraction of nitrogen, carbon dioxide, and water vapor in the gas. A wide variety of biomass feestocks have been gasified including wood, corn cobs, wheat straw, rice hulls, nut shells and fruit pits. Though much effort has been devoted to coal gasification, the high volatile content of biomass makes it easier to gasify than coal. The foremost biomass feedstock for gasification is wood.

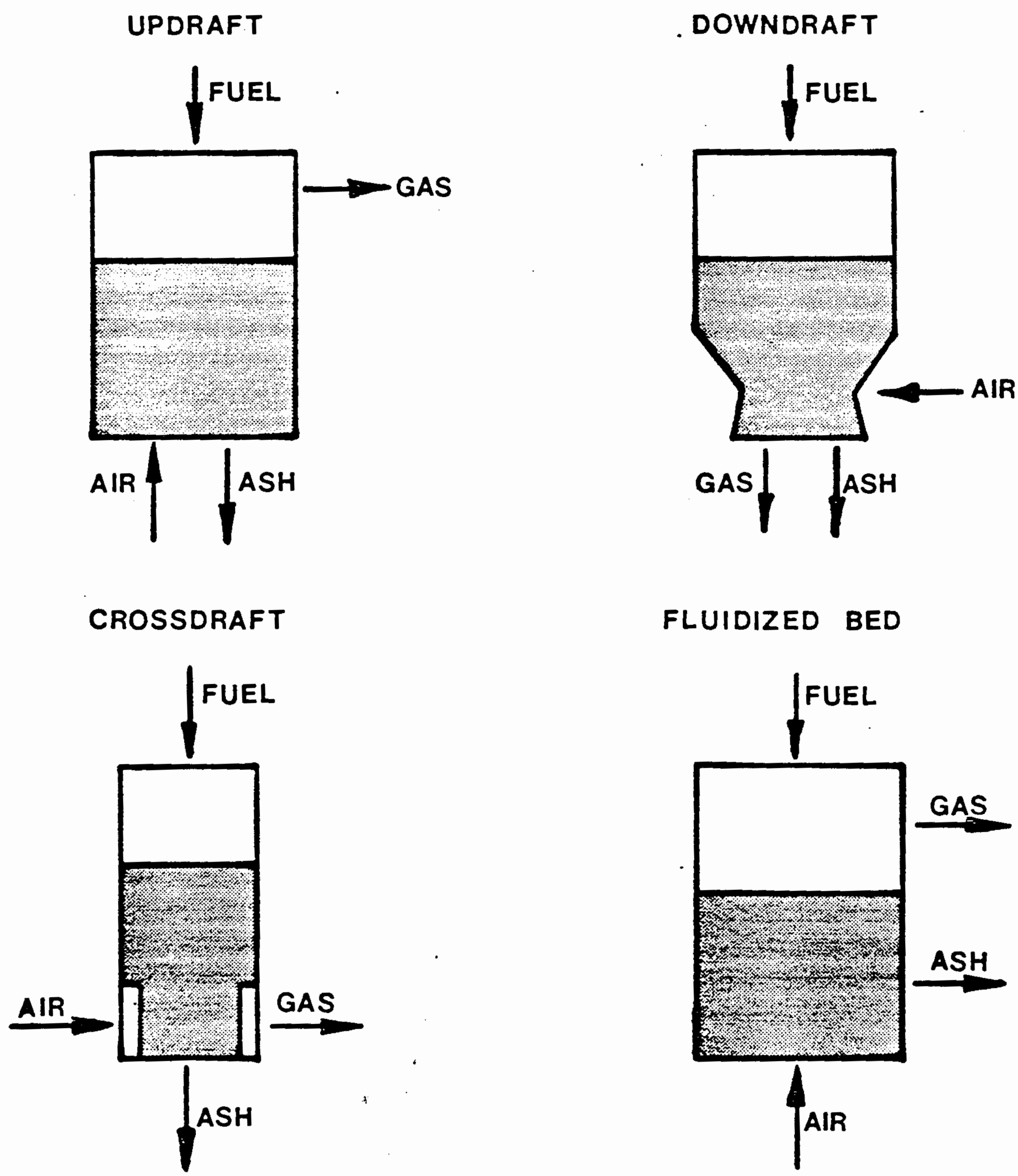
Technical Information

Gasification technology dates back to the nineteenth century. Before natural gas became readily available by pipeline, gasification installations were widespread. Today's energy shortages have resulted in a renewed interest in gasification, and although several demonstration systems have been operated the process is not yet fully commercial. Gasifiers are feasible in a broad range of outputs. Sizes ranging from approximately 1 million Btu/hr. to 80 million Btu/hr. are available. Biomass gasification appears to be best suited to applications of 25 million Btu/hr. output and larger.

The greatest determinant on gas production rate and composition is the geometry of the bed (McGowan, 1982). Four general types exist - updraft, downdraft, cross-draft and fluid bed (Figure 1.5). Updraft units can accept wet wood feed in a variety of size ranges. The unit is large and capital costs are high. The gas produced is low temperature and contains a large amount of tar. Downdraft gasifiers are more compact and produce less tars. They are limited to feed with moisture contents of 30% or less and have rarely been built in large output sizes. Crossdraft units have been used to produce fuel gas for internal combustion engines. They feature fast startup and high turndown and capacity but are also limited to dry fuel. Fluid bed gasification units are a recent development which promise greater capacities than fixed bed types. Tars are apparently cracked in the bed yielding a high quality gas.

Figure 1.5

Bed Geometry in Wood Gasifier



A limitation on gasifiers is the tar content of the gas. A typical wood gas analysis is shown in Table 1.8. In addition to these gaseous constituents, liquid droplets and mists are evolved during the thermal decomposition of wood. In downdraft gasifiers the liquids are cracked as they pass through the hot bed; however, in updraft units they are entrained with the gaseous fuel products. For situations where close coupling of the gasifier and burner is possible tar compounds present no major problem as they are burned along with the gas. If the gas must be transported any distance or if the application requires a clean fuel, scrubbing may be necessary. Since the tar compounds do have energy value, scrubbing lowers the heat content of the biogas and reduces the gasifier efficiency. Typical values for efficiency are in the range of 80-90 for unscrubbed gas and 50-60 for cleaned gas (Bulpit, et al., 1981).

The form of biomass accepted by a gasification unit is determined largely by the geometry of the vessel. Updraft and downdraft configurations are best served with larger pieces of material such as wood chips. Fines and other small material can plug the bed and restrict the flow. Fluidized bed gasifiers accommodate various material sizes from fines through chips. Extremely large pieces must be avoided as they cannot be fluidized and end up falling to the bottom of the reaction zone.

Turndown ratios in the range of three or four to one are common for gasifiers. Major subsystems of the gasifier include ash removal, steam supply and combustion. The gasifier is started by introducing a heat source into the unit. Once combustion is self-sustained, the reaction vessel can be closed and fuel-air ratio control initiated. Steam injection is utilized for hot zone cooling particularly in units without water jackets. Injection of steam can improve gas quality in some instances by promoting "shift reactions" yielding higher hydrogen content in the gas. Steam is not always necessary in water cooled systems, however.

The utilization of biomass gasifiers in industrial situations to date has consisted of updraft, fixed bed and fluid bed gasifiers. A demonstration 25 million Btu/hr. unit to supply low Btu gas fuel for a hospital's 19,000 lb./hr. boiler was commissioned in Georgia during late 1980 (Bulpit, 1980). Recently Florida Power Corporation announced plans to supplement their power plant near Live Oak with wood gas. Again a 25 million Btu/hr. gasifier will be employed to supply fuel gas to one of the six burners on a 350,000 lb./hr. boiler (Jackson, 1982).

Table 1.9

Typical Wood Gas Analysis

Gas	Composition Dry Basis	By Volume, % From 50% M.C. Wood
N_2	50	34.1
CO	20	13.6
CO_2	15	10.7
H_2	12	7.3
CH_4	3	2.2
H_2O	0	32.6

Source: Economic and Technical Design Manual for Wood Systems, T.F. McGowan

Economic Data

Gasifiers are not suited to every application, but they exhibit many operational characteristics that support their utilization. Biogas is attractive because it can replace fossil fuels directly without concerns about contamination. Gasifiers offer the only alternative for converting gas/oil package boilers to biomass fuel. Inability to store gas effectively and low heating value generally prohibit transportation, but is is an excellent choice for many on-site energy needs. The major drawbacks to the wide aceptance of gasification systems is the sophisticated technology involved and the large plant size required to achieve economical production. Current estimates of gasifier costs place the price of a 1 million Btu/hr. unit in the range of $25,000-$45,000 (Brown, 1982). Maintenance costs are in the range of 5% of the capital cost annually.

Operating costs were developed from data on wood boilers and they include labor and utilities. Operating costs increase linearly with gasifier size. Since small systems have approximately the same labor requirements as larger ones, the operating cost is a larger percentage of the small system capital cost. Table 1.10 summarizes the operating costs for a 25,000,000 Btu/hr. gasifier.

Table 1.10

Operating and Maintenance
Costs for Gasifiers

Output	=	25,000,000 Btu/hr.
Capital Costs	=	\$720,000
Maintenance	=	\$36,000 (5% of Invested Capital, .05 x \$720,000)
Labor and Utilities	=	\$43,200
Total	=	\$79,200
Unit Cost	=	$\frac{\$79,200}{25}$ = \$3200/million Btu/hr.

Feedstocks

The primary feedstock used with biomass gasifiers has been wood. Updraft gasifiers can tolerate green (50% moisture content) wood, but this is not the case with downdraft units. When selecting feedstocks the particle size of the material is an important property to keep in mind. Extremely small particles such as wood fires can become packed in the gasifier bed and restrict air flow to the point of causing a shutdown. Therefore, the best operation is obtained on larger size material. While gasifiers would be suited to operation on agricultural residue of the right moisture content and size, very little progress has been made in this area.

1.5 Methanol Production from Biomass Gasification

Process Description

As was discussed in the previous section, gasification is an attractive conversion process for many on-site energy needs. Wood gas is typically not transportable though, and the production of methyl alcohol (methanol) from wood gas will yield a transportable fuel suitable for chemical feedstock, boiler, and engine application. Much interest has been focused on methanol for use as a gasoline substitute and extender. Methanol is an extremely clean fuel and it may be substituted for other petroleum fuels in many instances even though its heating value is lower. Currently most methanol is formed from natural gas feedstock. Methanol production from biomass is a gasification/synthesis process derived originally from coal technology.

For solid carbonaceous material to be formed into methanol, it must first be transformed to a mixture of H_2, CO and CO_2 through gasification. Other process steps include gas clean-up, shifting, synthesis and fuel blending. Methanol synthesis gas consists of a mixture of 2 parts hydrogen, 1 part carbon monoxide, and trace amounts of carbon dioxide. If air gasification is used the nitrogen must be removed cryogenically. Removal of material besides hydrogen and carbon monoxide such as nitrogen is important since higher pressures are required to minimize "inerts" in the methanol as the amounts of impurities increase. Oxygen blown gasification is one promising approach to methanol production since the nitrogen removal step would be eliminated. Gas clean-up involves removal of sulfur and excess carbon dioxide as well as particulates, oils, and tars. Because methanol is synthesized from a mixture of two parts hydrogen and one part carbon monoxide, the volume of these two constitutes in the biogas must be adjusted to this ratio. Synthesis gas with a 2:1 ratio of hydrogen to carbon monoxide is formed in a shift reactor by reacting part of the CO with water to form additional hydrogen as shown below:

$$H_2O + CO \xrightarrow{\text{catalysts}} H_2 + CO_2$$

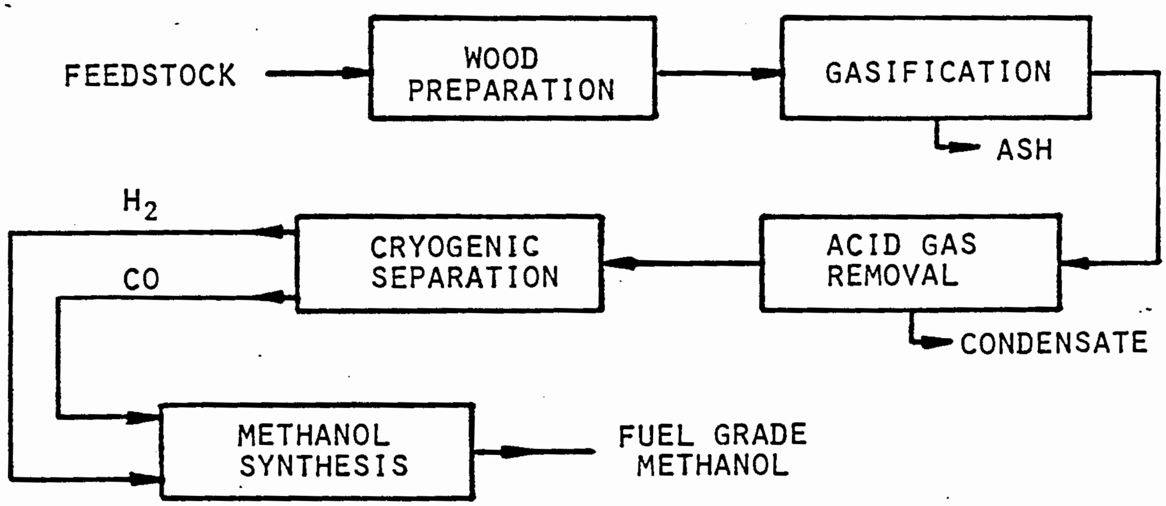
Methanol can be formed in the synthesis step by a zinc-chromium catalyst at high pressure (2000-4000 psi) or by a copper catalyst at moderate pressure (1000-2000 psi) (Cheremisinoff, 1979). In the shift reactor approximately 95% of the gas is converted to methanol. The crude methanol product then passes through the reactor and is distilled to remove the light ends and higher alcohols. The steps of the methanol synthesis process are summarized in Figure 1.6.

Technical Information

The trend in methanol plant design has been toward large scale facilities. Current economic sizes of methanol plants are between 50 and 200 million gallons per year of output. A readily available supply of feedstock is one prerequisite when a methanol facility is considered since a 50 million gallon per year operation wood

Figure 1.6

Process Diagram For
Production of Methanol



require 1500 tons of wood per day. The wood requirement is high due to the low efficiency of the wood to alcohol process. Process efficiency is defined as the ratio of the heating value of the methanol produced to the heating value of the input feedstock. For natural gas, this efficiency is 91%, but for wood it is only 50%. Another instructive parameter useful when investigating large scale conversion processes is the plant efficiency. This is defined as the ratio of the heating value of the plant output to the total energy input into the plant. For a wood waste to alcohol facility the plant efficiency is approximately 38%.

Methanol could become an important fuel source for internal combustion engines in transportation and stationary power generation, but with a heating value of 8600 Btu/lb., it has only about 1/2 of the energy content of gasoline. Furthermore, the heat of vaporization for methanol is about four times that of gasoline. This factor greatly complicates carburation in an internal combustion engine. Recent shifts in governmental policy toward alcohol utilization have left the future of widespread alcohol production and consumption in doubt. With the large sizes of methanol plants required for economical production costs and the accompanying large investment costs and feedstock demand, siting of a facility in the southeast seems doubtful. Another major barrier to an operating wood to methanol plant is the lack of a commercial gasifier capable of offering the availability and reliability required. While the processes associated with methanol production from natural gas are well understood, methanol production from wood retains a degree of technical risk.

Economic Data

A wood-to-methanol facility is estimated to cost roughly three times that of a conventional natural gas-to-methanol plant because of the simplicity of the natural gas conversion process. In 1975, the estimated cost of a 50 million gallon per year wood waste methanol facility was 64 million dollars. The same size facility for natural gas would cost 23 million dollars (Hokanson and Powell, 1977). Operating costs for a methanol plant includes raw material, fixed costs, and labor costs. Annual maintenance cost is estimated to be 4% of the initial investment. The methanol facility considered in this study included steam turbines for electrical power generation thus no external utilities are required. The estimated labor cost is 1.2

million and includes operators, foreman, and managers. Table 1.11 summarizes the operating and maintenance costs for a methanol plant.

Feedstock

Wood is the most feasible biomass feedstock for methanol production because it is available and economical. Other varieties of biomass, such as agricultural residue, could help supplement the wood requirement but are not available in sufficient quantity year round to be a primary feedstock.

Table 1.11

Operating and Maintenance Costs for Methanol Facility

Output: 50,000,000 gal./yr.

Maintenance	=	\$2,560,000 (.04 x 64,000,000)
Labor	=	\$1,200,000
Total		\$3,760,000

Production = 5710 gal./hr. x 64,600 Btu/gal. = 368.8 million Btu/hr.

Unit Cost = $\frac{3,760,000}{368.8}$ = \$10,195/million Btu/hr.

1.6 Methane Production by Anaerobic Digestion

Process Description

It has long been established that the decay of organic materials will produce methane gas. The process involves the interacting of microbial species that decompose the organic materials into organic acids, then from H_2 and CO_2 from which methane is synthesized (Bungay, 1981). The initial application of anaerobic digestion was sewage treatment plants where primary sludge (the settled fraction of sewage) is converted to partially sanitized, comparatively odorless digested sludge, and methane gas. Digestion occurs in large concrete or metal tanks. Mechanical arms or pumps mix the material and heat exchangers are used to maintain the temperature at 90-

100°F. The design of digesters for municipal and animal waste is a well developed technology. The widest application of anaerobic digestion has been with municipal wastes, however the increasing price of natural gas has caused methane production from animal wastes to be economically practical in some instances.

Technical Information

Primarily there are two temperature ranges of economic importance with anaerobic digestion, 1) Mesophilic with an optimum temperature of 95°F and 2) Thermophilic with 140°F the optimum. Process design decisions to be considered include reactor flow method (batch, continuous, or semi-continuous), the feed slurry concentration, solids retention time, and operating temperature (Jones and Fong, 1978). Operating the digester at higher temperature reduces the retention time required for optimal digestion, but due to the higher operating and maintenance costs associated with eleveated temperature operation, it is scarcely employed. The solids retention time associated with mesophilic operation is on the order of 20 days versus approximately 10 days for thermophilic operation. Even with the digester operating at 95°F, approximately 15-25% of the energy evolved must be used for digester heating which reduces the overall efficiency of this process (Jones and Fong, 1978).

Digestion begins when sewage or other degradable feedstock having a solids concentration of 5-10% dry matter is fed into the vessel. Highly degradable feedstock can yield as much as 8-9 ft^3 of gas (containing 50-70% methane) per pound of solid input (National Academy of Sciences, 1977). The process efficiency for anaerobic digestion is generally in the range of 35-50%. Typical composition of digester gas is 60% CH_4 and 40% CO_2. The heating value of this gas is approximately 500 Btu/ft^3 (National Academy of Sciences, 1977).

The size of anaerobic digesters is limited by economic considerations on the small end of the scale, and feedstock availability on the large end. Small community digesters down to a size of 100 $ft.^3$ have been constructed in underdeveloped third world countries. Large, continuous flow digesters for sewage treatment in this country reached over 100,000 $ft.^3$ in volume.

Anaerobic digestion, though not a widely applied technology, is considered commercial. Recent applications of anaerobic digestion have focused on community batch feed units in developing nations. Domestic systems tend to be large scale continuous processes. A recent analysis indicated that a 4,000 head feedlot would probably be the minimum economic size (National Academy of Sciences, 1977). Advantages and disadvantages of anaerobic digestion are summarized in Table 1.12.

Table 1.12

Advantages and Disadvantages of Anaerobic Digestion

ADVANTAGES	DISADVANTAGES
1) Produces high grade gaseous fuel	1) High capital costs
2) Sludge is valuable fertilizer	2) Gas may require cleaning and concentration before use
3) Treated sludge minimizes health hazards	3) A large volume of waste material is developed since water is added to substrate
	4) Proper operating conditions must be maintained for maximum gas production

Economic Data

Costs associated with anaerobic digestion facilities have been developed. The capital cost of 9.4 million Btu/hr. output, 10,000 head system are shown in Table 1.13. The capital cost per million Btu/hr. of output for this plant would be \$165,000. The plant costs includes ponds for wastewater evaporation and a sludge handling system for solids processing. Table 1.14 summarizes the operating costs for the same size digestion facility. These costs are for medium Btu gas (60% CH_4, 40% CO_2). Any upgrading of the gas would entail additional cost.

Feedstocks

The raw materials that can be considered as substrates for methane generation are natural organic materials, generally cellulosic in composition. Typical materials include crop residues, paper wastes, animal manures, and human wastes. The ratio of carbon to nitrogen in the feed is important in determining the efficiency of methane

Table 1.13

Estimated Capital Requirement for Anaerobic Digestion Plant

Plant Area	Cost (thousands of dollars)
Feedstock Pumping and Storage	267
Feedstock Preprocessing	152
Biochemical Conversion	534
Solids Processing	297
Wastewater Evaporation	300
Total	1,550

Source: Mission Analysis for the Federal Fuels from Biomass Program, Volume V, J. Jones, 1978.

Table 1.14

Operating and Maintenance Costs for Anaerobic Digestion

Output = 9,400,000 Btu/hr.
Electricity = $.04/kw/hr.
Labor Cost = $10/hr.

Maintenance (5% of Invested Capital)	$77,500
Utilities (588,700 kw-hr.)	23,550
Labor (1.5 men shift)	126,000
	227,050

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production. If the carbon/nitrogen ratio is too high the process is limited by the available nitrogen. If this ratio is too low, ammonia may be formed in quantities sufficient to inhibit further bacteria growth. A carbon to nitrogen ratio near 30 is considered best to achieve the optimum methane production (National Academy of Sciences, 1977). Carbon/nitrogen ratios for several common materials are shown in Table 1.15.

Experience has shown that gas production can be increased by supplementing substrates that have a high carbon content with nitrogen containing feeds, and vice versa to attain a carbon/nitrogen ratio of 30.

Table 1.15

Carbon/Nitrogen Ratios for Common Materials

Material	Carbon/Nitrogen Ratio
Horse Manure	25
Cow Manure	18
Human Waste	6-10
Grass Clippings	19
Cut Straw	48
Sawdust	511

Source: Methane Generation from Human, Animal, and Agricultural Wastes, National Academy of Sciences, 1977.

Because of the diverse nature of feed materials used for anaerobic digestion, appropriate methods of preparation must be provided. When materials such as straw, hay, and bagasse are used it is recommended that they be shredded into small pieces to facilitate flow and increase gas production. Many organic materials, particularly woody biomass, has a slow rate of digestion due to the lignocellulose present. Because of the difficulty encountered in digesting these materials, either direct combustion or gasification is preferred.

1.7 Summary

Table 1.16 summarizes the data for biomass energy systems. Both technical and economic data is included in the table. In addition to the information on biomass systems, the Table contains an entry on conventional gas/oil boilers for purposes of comparison. In most instances the initial cost and the operating and maintenance cost are dependent on equipment size. A range of costs are given to encompass the high and low ends of the output scale. In cases where a single value of cost is given, the equipment size associated with the cost is also noted.

Table 1.16
Biomass Energy Systems Data Summary

	Initial Cost	Operating and Maintenance Costs Excluding Fuel	Size Ranges	Turn-down Ratio	Efficieny	Estimated Useful Life	Output Steam	Hot Air	Gas	Liquid
DIRECT COMBUSTION										
Stickwood fp or non-										
airtight	$75-250	$50/yr. maint.	20-50kBtu/hr.	2:1	-10-+30	20 yrs.	x			
airtight	$300-800	$50/yr. maint.	20-50kBtu/hr.	2:1	20-65			x		
furnace	$500-8000		30-200kBtu/hr.	3:1	40-60			x		
Wood Chip & Pulv.										
thin bed	$30/lb.	$5.10/lb.	2000-500,000 lb./hr.	4:1	65-75	20 yrs.	x			
sloping grate	($30,000/mmBtu/hr.	$5100/mmBtu								
traveling grate		(50,000 lb./m)								
pile burning (heaped)	$30/lb.			3:1	60-70		x			
Dutch Oven	($30,000/mmBtu/hr.									
Cell burner										
suspension	$300k/15 mmBtu/hr.	$1250 mmBtu	5-60 mmBtu/hr.	5:1	95	20 yrs.	x			
fluidized bed	$500/10 mmBtu/hr.	$8.8/lb.								
		$8800/mmBtu	5-120 mmBtu/hr.	3:1	70-75	20 yrs.	x			
PYROLYSIS/LIQUEFACTION										
Pyrolysis	20k-40k per									
	mmBtu/hr.	$5600/mmBtu	10-200 mmBtu/hr.		85-95	20 yrs.			x (char)	
Liquefaction	$60 million for									
	24 mg/yr.pt.	$13,200/mmBtu/			60					x
GASIFICATION										
updraft	25k-45k/per									
	mmBtu/hr.	$3200 mmBtu/	1-80 mmBtu/hr.	4:1	80-90	20 yrs.		x		
					(dirty)					
downdraft					50-60					
					(clean)					
crossdraft										
fluid bed										
METHANOL PRODUCTION	64mm/50mg/yr.	$10200/mmBtu	50-200 mgpy	-	50%	20 yrs.				x
Anaerobic Digestion	1.55mm/9.4mmBtu	$24100/mmBtu	50,000-50 mmBtu/hr.	-	50%	20 yrs.			x	
CONVENTIONAL (gas/oil)										
BOILER	$3-5/lb.	$1.71/lb.	2000-600,000lb./hr.	5:1	80-90%	20 yrs.	x			
	(3000-5000/									
	mmBtu/hr.	$1700/mmBtu								

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CHAPTER 2

DEVELOPMENT OF BIOMASS UTILIZATION SCENARIOS

INTRODUCTION

The environmental impacts of harvesting and collecting biomass for use as an energy source depends not only on the rates at which impacts occur but the quantity and source of biomass materials devoted to energy as well. This quantity is a function of the demand and supply markets for both biomass and other energy sources. The demand for biomass materials for energy depends on a large number of extremely complex interdependent and highly dynamic systems. Because the demand-side markets for energy are mature, however, it is not unreasonable to assume that the demand for biomass as an energy source is highly price elastic over the long run. Because coal is a common competitor of biomass energy systems, it further seems reasonable that the more highly developed coal markets could be assumed to provide the maximum price at which the market would purchase biomass materials for energy. An implicit assumption regarding the use of biomass technologies is that the technology penetration process has been allowed to run its course. That is, this analysis should be considered as long-run. The determination of the quantity of biomass used for energy then becomes the more manageable, but still complex, problem of forecasting a supply response to a given market price. The complexity of the supply response lies in the fact that biomass materials are produced via vastly different production functions. The market supply curve is, therefore, composed of a number of component overlapping supply curves with the market supply curves being the minimum cost alternative for each quantity. The goal of this section of the report is to estimate this market supply curve and use it, with energy price scenarios, to estimate a quantity of biomass devoted to energy use. This quantity is then used to quantify, to the maximum extent possible, the environmental effects thus implied.

1.1 Sources of Supply

The major supply source for biomass energy is, of course, foresty-related. Within forestry, however, there is a multitude of sources some of which are, for all practical purposes, totally price inelastic at some quantity while others could be expected to show some degree of price responsiveness. Those which are price inelastic are those biomass sources which exist as a derivative of some other production process. The most clear example of this is residue resulting from lumber milling. The purpose of a lumber mill is to produce lumber. It is unlikely that a change in the price of their milling residues will cause either significantly more, or less, lumber to be milled. The characteristics of the mill residues, therefore, is that virtually all of the residues are collected for about the same cost -- but beyond that quantity, no reasonably expected price increase would invoke a greater supply quantity. The cost estimate for this source of biomass energy, as depicted on Table 2.1, is \$.60 per million BTU and represents the lowest cost biomass material in forestry.

The next most available source of forestry biomass is also a derived-supply as was mill residues. It consists of all of the forest components typically left in the forest following logging operation including tops, culls, limbs and stumps. Some of these items can be collected at low cost while others would cost much more. All collectable logging residues would have transportation costs as well as collection costs. It has been estimated that the average cost for these residues is \$1.40 per MMBtu. It is further assumed that the cost function for these residues is symmetric with the 50th percentile quantity costing the average, i.e., \$1.40 per MMBtu. Lower quantities would be cheaper though not greatly so because of the large transportation cost component. Greater quantities, however, would experience a rapid use in costs due to the relatively higher labor associated with, for example, stump collection.

Thinnings are another source of biomass which are partially elastic with respect to energy prices. As forests mature it is common practice to periodically remove the less desirable plants or reduce the density to allow faster growth in the stand. There is great latitude in the timing of this activity as well as its extensiveness. In general, however, the thinning process is more controlled by the economics of the first-use products ultimately harvested. Furthemore, the annual quantity of thinnings available, though possibly fluctuating from year to year in response to energy prices, is not likely to change greatly on average. The average price for thinnings has been estimated to be \$1.90 per MMBtu. Like collectable residues, it is probable that the supply curve is relatively flat at quantities below the fiftieth percentile but rises steeply at greater quantities.

A less tractable, but significant, potential source of biomass energy is found in the conversion of scrub hardwoods to softwood plantation. The intractability of this source lies in the fact that it is a one-time occurrence for any given plot of land. Also, as with milling residues, it is a source of biomass which would result from a complex process involving, primarily, issues other than energy prices or availability. For this reason, it has been assumed that the equivalent annual impact of conversion would be 10% of that quantity estimated to be available in our forecast year of 2000. The price for this biomass has been estimated to average $2.00 per MMBtu, i.e., it is slightly higher than thinnings.

Table 2.1

Assumed Average Prices for Alternative Sources of Biomass per MMBtu

Milling Residue	$ .60
Collectable Residue	$ 1.40
Thinnings	$ 1.90
Conversions	$ 2.00
SRWC	
Idle cropland	$ 2.21
Average-all types	$ 7.90

Source: Dunwoody, Inc.

The final, and potentially, the greatest source of biomass energy comes from increases to current biomass production motivated, primarily by energy related issues. The most significant method by which this could be accomplished would be by short rotation woody crops (SRWC). At the present time, there is no significant utilization of SRWC as an energy source in the southeastern states. Whether or not SRWC becomes a major source of energy depends upon the economic factors involved. It has been estimated that the average cost for energy from SRWC would be in the neighborhood of $7.90 per MMBtu which is prohibitively high given current alternative energy prices and availability. Like the other biomass sources, however, a range exists for prices at which some lesser quantitities can be economically provided. For example, it has been estimated that the cost of providing SRWC biomass from otherwise idle cropland would be only $2.21 per MMBtu.

A summary of the supply sources and their estimated prices are given on Table 2.1.

2.1 Market Supply Curve

The market supply curve for each state within the region is approximated by performing a least squares regression on points identified as being on the component supply curves. The prices for each observable quantity are given on Table 2.1. The quantities available at each price were derived by analyzing forestry activity and resource availability. These estimated quantities are presented on Table 2.2. The supply curve was then constructed by summing the marginal amounts to arrive at a total amount estimated to be available at each price. These quantities are provided on Table 2.3. Observations were not available for all sources for all states. A discussion of the methodology used to derive each point is included as Appendix A. A graphical representation of how these observations are used is given of Figure 2.1. It is important to note that the shapes of the component supply curves pictured are hypothetical. The results of the regressions are given on Table 2.4.

Table 2.2

Estimated Marginal Biomass Supply
by Source Year 2000
(10^6 DT)

	Milling Residue Softwood	Hardwood	Collectable Residue Softwood	Hardwood	Thinnings	Conversions Softwood	Hardwood	Idle Cropland	SRWC
AL	1.67	2.44	6.92	20.08	1.45	8.92	10.70		22.12
FL	1.40	1.44	7.32	12.48	.04	3.93	4.72	1.40	3.23
GA	1.64	1.70	6.76	15.17	.09	9.44	11.33	3.36	7.74
KT	.01	1.05	.04	8.73					
MS	1.48	2.72	6.09	22.59	1.15	7.02	8.42		17.42
NC	1.58	3.71	8.38	32.09	.08	7.81	9.37	2.76	6.41
SC	.98	2.30	5.19	19.91	.05	4.52	5.42	1.61	3.71
TN	1.12	2.07	4.62	17.14	1.03	6.33	7.60		15.69

Data sources and estimation methodology given in Appendix A.

Table 2.3

Estimate Total Biomass Supply Quantity
by Price Per MMBtu For Each Price Year 2000
(10^6 DT)

	\$.60	\$1.40	\$1.90	\$2.00	\$2.21	\$7.90
AL	4.11	17.61	18.34	19.41		41.53
FL	2.84	12.74	12.76	13.23	14.63	16.46
GA	3.34	14.31	14.35	15.48	18.84	23.22
KT	1.06	5.45				
MS	4.20	18.54	19.12	19.96		37.38
NC	5.29	25.53	25.57	26.50	29.26	32.91
SC	3.28	15.83	15.86	16.40	18.01	20.11
TN	3.19	14.07	14.59	15.35		31.04

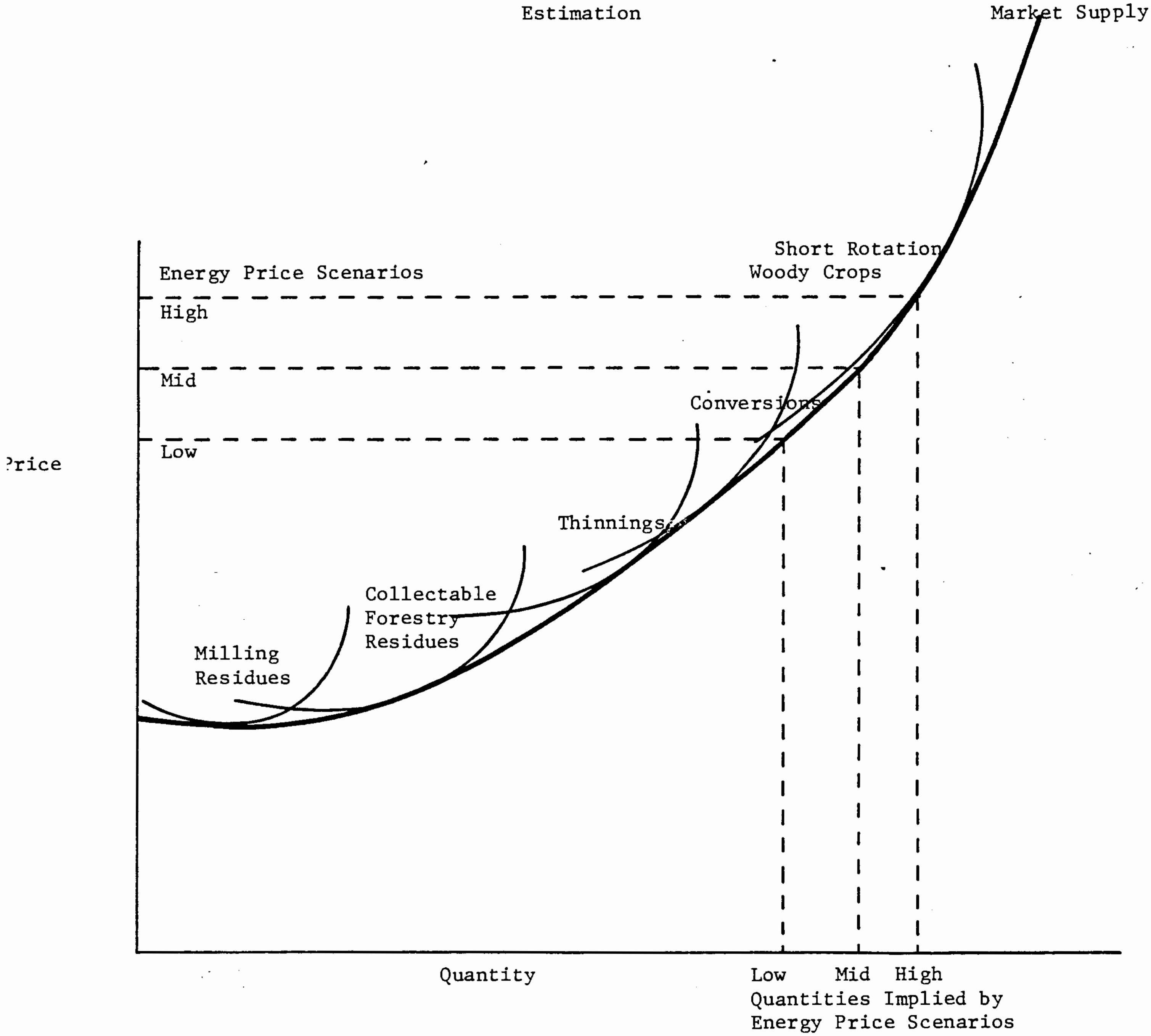
The equations implied by the coefficients given on Table 2.4 are used to estimate biomass energy utilization rates from forestry by substituting the energy price scenarios prepared by the Department of Energy Energy Information Agency in their latest report to Congress. Because of the similar handling and use characteristics, coal is the appropriate price scenario to utilize. The year 2000 estimates were not provided by DOE. They were, therefore, derived as follows:

1. Extrapolations were made to the year 2000 using four different methods, i.e., linear average rates of growth, logarithmic average rate of growth, time series regression, and logarithmic time series regression.
2. The lowest and highest of the twelve resulting data points were taken as low and high price scenarios. The mid-price scenario was taken as the average of the sixth and seventh data points.

This procedure has the effect of increasing the range of scenaios - which is appropriate considering that the projection is further into an uncertain future. The final energy prices used in the scenarios are given on Table 2.5.

These energy price scenarios are used to estimate forestry biomass energy utilization from the relationships implied by the market supply curves previously constructed. The resulting low, medium and high utilization levels presented on Table 2.6 for each state. It should be noted that the data available for Kentucky were very

Figure 2.1
Graphical Representation of
Biomass Market Supply Curve
Estimation



Talbe 2.4

Estimated Biomass Supply Curves By State

ALABAMA

$$\ln X = \underset{(11.1)}{2.23364} + .841196 \ln P \qquad R^2 = .87$$

FLORIDA

$$\ln X = 2.09851 + .625722 \ln P \qquad R^2 = .62$$

GEORGIA

$$\ln X = \underset{(8.3)}{2.03949} + \underset{(2.9)}{.687148} \ln P \qquad R^2 = .74$$

KENTUCKY*

$$\ln X = .5715 + .4886 P$$

MISSISSIPPI

$$\ln X = \underset{(10.1)}{2.27652} + \underset{(3.7)}{.786375} \ln P \qquad R^2 = .82$$

NORTH CAROLINA

$$\ln X = \underset{(8.1)}{2.57581} + \underset{(2.2)}{.631750} \ln P \qquad R^2 = .62$$

SOUTH CAROLINA

$$\ln X = \underset{(6.7)}{2.10573} + \underset{(1.9)}{.580351} \ln P \qquad R^2 = .55$$

TENNESSEE

$$\ln X = \underset{(9.3)}{1.99871} + \underset{(2.2)}{.823212} \ln P \qquad R^2 = .85$$

X = biomass quantity in 10^6 Dry Tons
t - statistics in parenthesis

*Only two data points were available for Kentucky so a simple logarithmic equation was fitted. R^2 and t-statistics are therefore not available.

Table 2.5

Energy Price Scenarios
Year 2000
(1980s $)

	Per 10^6 Btu
Low	2.858
Mid	3.131
High	3.718

Table 2.6

Total Estimated Biomass Utilized For Energy
By State and Fuel Price Scenario Projected to Year 2000
(10^6 Mg)

	Nonenergy Delivered to Plant	Low	Mid	High
AL	14.12	20.48	22.12	25.55
FLA	10.24	14.27	15.10	16.82
GA	12.05	14.35	15.28	17.19
KY	2.77	6.50	7.43	9.88
MISS	13.89	20.18	21.68	24.82
NC	16.90	23.14	24.52	27.33
SC	10.40	13.71	14.45	15.97
TN	10.54	15.89	17.14	19.74

much incomplete. The effect of this is that component supply curves for production functions producing biomass at higher prices are under-represented. This results in a market supply equation for Kentucky which is somewhat less responsive than those estimated for the other states in the region. Countering this is the fact that coal prices are likely to be somewhat less in Kentucky due to lower transportation distances. Lower coal prices would tend to bias this analysis in the opposite direction.

These two biases tend to cancel one another out so that the resulting direction of bias is indeterminant but, hopefully, small.

It is recognized that forestry biomass is not the only source for biomass supply. The other two major potential sources are from aquaculture and agriculture. The economics for aquaculture are not favorable presently or in the foreseeable future except, conceivably, where the bimoass is a by-product of some other process such as municipal wastewater treatment. Even then, the high moisture content of these fuels increases transportation costs and reduces effective energy content for combustion making them not a premium fuel. Agricultural biomass is a more viable potential fuel but it, too, suffers from characteristics which reduces the possibility that it's use would be significant relative to forestry biomass except it specialized circumstances. For thse reasons, the lack of price-quantity observation from these biomass supply sources should not introduce any serious biases to the estimated market supply curves.

The specification of a market supply curve in this fashion provides a good estimate for energy used from biomass sources but is imperfect in specifying the source from which the biomass was supplied. Insight into the composition of biomass can be gained, however, by analyzing the availability of biomass from each potential major source. Employing the same assumptions of cost behavior for each source previously discussed, the total biomass quantities can be approximated. The motivation for defining the likely sources of biomass is that each source can have different environmental impacts. Insufficient data exist to specify the proportion from nonforestry sources. Table 2.7 presents the estimated disagregation of the total biomass into the major sources. To complete the table for each scenario it was necessary to assume that biomass in excess of that identified would be secured through increases to growth over what would be expected in the absence of energy markets for biomass. The incremental growth is further assumed to be harvested with impacts analogous to "harvest with residual collection" described on Tables 3.1 through 3.4. The type of biomass thus harvested is further assumed to be analogous to hardwoods as softwood would generally have a higher use.

Table 2.7

Disaggregation of Total Estimated Forestry Biomass Utilized for Energy into Major Sources by State for the Year 2000 for Three Energy Price Scenarios (10^6 Mg)

	Milling	Collected Residue				Biomass Demand Increases to Growth		
	Residue	Hardwood	Softwood	Thinnings	Conversion	Low	Mid	High
AL	3.73	9.11	3.14	1.32	.97	2.21	3.85	7.28
FLA	2.58	5.66	3.32	.04	.43	2.24	3.07	4.79
GA	3.03	6.88	3.07	.08	1.03	.26	1.19	3.10
KY	.96	3.96	.02			1.56	2.49	4.94
MISS	3.81	10.25	2.77	1.04	.76	1.55	3.05	6.19
NC	4.80	14.55	3.80	.07	.85	0.0	.45	.96
SC	2.98	9.04	2.36	.05	.49	0.0	0.0	1.05
TN	2.89	7.77	7.10	.93	.69	1.51	2.76	5.36

CHAPTER 3
ENVIRONMENTAL IMPACTS

INTRODUCTION

This analysis of environmental impacts proceeds in two stages. The first is an inventory of the various areas where impacts might be expeced to occur. The second stage synthesizes the results of the biomass utilization analysis with the environmental impact information to derive a more definite representation of the significance of the impacts. The first stage is analogous to other works done, for example, in other regions of the U.S. but concentrates on quantitative data. The second stage, however, represents a significant departure from previous works. Though it was not found to be possible to quantify impacts from all areas due to the paucity of data, the market mechanisms involved do provide insight into these areas.

3.1 Forestry

3.1.1. <u>Depletion of Soil Nutrients</u>

3.1.1.1 Environmental Impacts Inventory

The largest identified potential source of biomass for energy is forestry related materials. A problem with the use of these residues for energy is that the removal of the additional material will eventually lead to depletion of soil nutrients and humus in the forest. Rigorous analysis of long-term effects necessarily requires long-term research. Even a minimal direct analysis needs to extend over at least one harvest cycle which usually involves several decades. In the short term, the best that can be done is to analyze nutrient pools and flows and try to predict the ultimate effects of more intense harvesting. A research project designed specifically to acquire such information for a variety of forest types in the United States is currently underway (Mann and West, 1981; West, et al., 1981). Other important data relating to this topic have just become available (West and Mann, 1982). Data for four diverse locations in the Southeast have been excerpted from these reports and presented in rearranged form together with additional calculations in Tables 3.1 through 3.4. Included in the tables are measurements of biomass, nitrogen (N), phosphorus (P), potassium (K),

Table 3.1

Coweeta Mixed Hardwood Forest
Nutrient and Biomass Input/Output Profile

(crop rotation = 70 years)

	Biomass (Mg/ha)	Nutrients (kg/ha) N	P	K	Ca	Mg
I. Pools						
A. Soil						
1. Exchangeable		-	36	510	940	-
2. Total		6800	-	124,000	2,500	-
B. Litter	21	120	17	18	185	-
C. Shrubs	7	110	12	83	59	-
D. Wood	178	277	41	216	544	-
E. Total	-	7,307	-	124,317	3,288	-
II. Harvest						
A. Commercial	58	79	9	65	172	-
B. With residue	178	277	41	216	544	-
C. Residue Only	120	198	32	151	372	-
III. Input/year		21	0.2	1.6	4.9	-
IV. Output/year		13	0.1	5.6	9.8	30
VI. Net change/rotation						
A. No harvest		+546	+7 to +14	-280	-343	-
B. Commercial		+467	-2 to +5	-345	-520	-
C. With residue		+269	-34 to -24	-496	-887	-
VI. % Change/rotation						
A. No harvest		+7.5%	-	-0.2%	-10%	-
B. Commercial		+6.4%	-	-0.3%	-16%	-
C. With residue		+3.6%	-	-0.4%	-27%	-
VII. Average Annual Change						
A. No Harvest		7.8	.1 to .2	-4	-4.9	
B. Commercial		6.7	-0.3 to .07	-4.9	-7.4	
C. With Residue		3.8	=.5 to -.3	-7.1	-12.7	
VIII. Average Annual % Change						
A. No Harvest		.11%	-	-.003%	-.1%	
B. Commercial		.1%	-	-.004%	-.1%	
C. With Residue		.05%	-	-.006	-.2%	

Source: West and Mann, 1982.

Table 3.2

Oak Ridge Mixed Hardwood Forest
Nutrient and Biomass Input/Output Profile

(crop rotation = 70 years)

	Biomass (Mg/ha)	Nutrients (Kg/ha) N	P	K	Ca
I. Pools					
A. Soil					
1. Exchangeable		-	33	275	1080
2. Total		3080	1330	21770	1360
B. Litter	16	150[c]	11[c]	24[c]	203[c]
C. Shrubs	3.6	59	4	45	33
D. Wood	165	363	25	160	1084
E. Total	-	3652	1370	21999	2680
II. Harvest					
A. Commercial	64	110	7	36	310
B. With residue	165	312	22	125	1084
C. Residue Only	101	202	15	89	774
III. Input/year		6.9	0.6	4.2	4.6
IV. Output/year		3	0.5	10	20
V. Net change/rotation					
A. No harvest		+7.5%	+7	-406	-1078
B. Commercial		+163	0	-442	-1388
C. With residue		-39	-15	-531	-2162
VI. % Change/rotation					
A. No harvest		+13.4%	+0.5%	-1.8%	-40%
B. Commercial		+4.5%	0.0%	-2.0%	-56%
C. With residue		-1.1%	-1.1%	-2.4%	-80%
VII. Average Annual Change					
A. No harvest		3.9	.10	-5.8	-15.4
B. Commercial		2.3	0	-6.3	-19.8
C. With Residue		-.6	-.2	-7.6	-30.9
VIII. Average Annual % Change					
A. No harvest		.1	.01	-.03	-.2
B. Commercial		.06	0	-.03	-.3
C. With Residue		-.02	-.02	-.03	-.4

[c] Woody litter not yet included.

Source: West and Mann, 1982.

Table 3.3

Clemson Loblolly Pine Forest
Nutrient and Biomass Input/Output Profile

(crop rotation = 40 years)

	Biomass (Mg/ha)	Nutrients (Kg/ha) N	P	K	Ca	Mg
. Pools						
A. Soil						
1. Exchangeable	-	-	9	98	321	-
2. Total	-	1656	-	-	-	-
B. Litter	26	192	14	19	113	-
C. Shrubs	1.6	20	1.2	25	11	-
D. Wood	132	150	13	63	134	-
E. Total	-	2018	-	-	-	-
. Harvest						
A. Commercial	79	63	5	36	70	-
B With residue	132	150	13	68	134	-
C. Residue only	53	87	8	32	64	-
Input/year		14.1	0.9	2.9	3.6	1.4
Output/year		0.2	0.1	1.5	2.1	-
. Net change/rotation						
A. No harvest		+556	+32	+56	+60	-
B. Commercial		+493	+27	+20	-10	-
C. With residue		+406	+19	-12	-74	-
% Change/rotation						
A. No harvest		+27%	-	-	-	-
B. Commercial		+24%	-	-	-	-
C. With residue		+20%	-	-	-	-

Source: West and Mann, 1982.

Table 3.4

Florida Slash Pine Forest
Nutrient and Biomass Input/Output Profile

(crop rotation = 30 years)

	Biomass	Nutrients (Kg/ha)				
	(Mg/ha)	N	P	K	Ca	Mg
I. Pools						
A. Soils						
1. Exchangeable			12	190	465	145
2. Total						
B. Litter						
C. Shrubs						
D. Wood						
E. Total						
II. Harvest						
A. Commecial	108	162	10	38	143	32
B. With residue	142	345	13	47	173	47
C. Residue only	34	183	3	9	30	15
III. Input/year		4.0	0.2	0.8	1.6	0.6
IV. Output/year		0.4	0.1	0.9	1.9	-
V. Net Change/rotation						
A. No harvest		+108	+3 to 16	-3	-9	+18
B. Commercial		-54	-7 to -4	-41	-152	-14
C. With residue		-237	-10 to -7	-50	-182	-29
VI. % Change/rotation						
A. No harvest						
B. Commercial						
C. With residue						

Source: West and Mann, 1982.

Footnotes for Tables 3.1 - 3.4

Input = rain + dry fall + gaseous exchange. Does not include weathering of rock.
Output = runoff + leaching. Denitrifcation not included.
Pools are measued prior to harvest. Pool totals do not include roots or stumps.

Net change/rotation

= ((Input/year) - (Ouput/year)) x (# years/rotation) - Harvest

% change/rotation

= (Net change/rotation) ÷ (Total pool)

Original data from West and Mann (1982).

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calcium (Ca) and, in some cases, magnesium (Mg). The first two tables refer to locations with mixed hardwoods in the Southern Appalachians. These are at Coweeta on the North Carolina - Georgia border and Oak Ridge, Tennessee. The other two tables represent pine forests. Table 3.3 refers to Clemson, South Carolina, which has a loblolly pine forest, and Table 3.4 represents a slash pine forest in Florida. Thus the four locations represent well the types of forest found in the Southeast.

The amounts of the reported components have been measured in the various forest elements that are ready for harvest. The elements are soil, litter, wood, and other vegetation. In soil, both the total amount present (which is potentially available to trees), and the exchangeable fraction (which is immediately available) have been measured. The rate of addition of these elements to the forest by precipitation and airborn dust or aerosols has been determined. The natural loss of these elements in water has been measured as well as the nutrients contained in harvested material. At each of the four locations reported on here three different treatments have been applied to similar forests. The first was a control site which was left unharvested. The second was a site harvested in the usual commercial manner, i.e., residues remained. On the third site the logging residues were also removed. Thus, this study provides basic information for estimating the impact on soil nutrients of removing logging residues for energy production.

The difference between yearly inputs and outputs provides a measure of annual accumulation or depletion. This figure is then multiplied by the number of years per rotation to obtain an estimate of the accumulation or depletion per rotation.

For the harvested forests, the nutrients contained in the material removed from the forest is subtracted. This produces an estimate of the net change per rotation.

In order to gain an impression of how significant these changes are, it is also useful to put them in terms of the fraction of the nutrient present in the forest. This is done by dividing the net change per rotation by the total pool of the nutrient in question.

With no harvest, some nutrients appear to naturally accumulate and some to decline. In all four locations, nitrogen accumulates at a substantial rate. As a fraction of nitrogen present in the forest, the accumulation was 7, 13, and 27% per rotation at the three locations where the relevant measurements are availabe. Phosphorus inputs and outputs are both small, but there appears to be a net accumulation in all four locations. At the one location (Oak Ridge) where the fractional change can be calculated, the accumulation is 0.5% per rotation. Potassium presents a more varied picture. In the hardwood locations, it is being lost from the forest, while in the Florida location it is nearly in balance, and at Clemson it is accumulating. In the two hardwood locations, the fractional decrease is 0.2 and 2% per rotation. Data are not available for calculating the fractional change at the other two locations. Calcium is being lost at a surprisingly large rate at both hardwood locations and more slowly at the Florida location. At Clemson it is accumulating slowly. The fractional loss at the two hardwood locations is 10 and 40% per rotation. The input/output data for magnesium are very sparse. The only conclusion that can be drawn is that it is not accumulating rapidly at the Florida site. Even this limited conclusion must be considered very tentative.

The direct effect of harvesting is, of course, to increase the loss of material from the forests. Residue removal has a particularly high impact on nutrients because the residue has a higher concentration of nutrients than the logs. In the study under discussion, commercial harvesting caused a loss of nitrogen only at the Florida location. Residue removal created a small deficit at Oak Ridge, in addition. At Coweeta, logging with residue removal cut the nitrogen accumulation in half. At

Clemson, even intensive harvesting reduced nitrogen accumulation by only a small proportion.

The impact of harvesting appears to be greater on phosphorus. At the three locations besides Clemson, commercial harvesting reduced the natural accumulation of phosphorus to an approximate balance and intensive harvesting created a decrease in phosphorus at about twice the rate of the natural accumulation. At Clemson even intensive harvesting reduced the rate of accumulation by less than half.

The impact on potassium is more diverse. At Coweeta, the natural loss is approximately doubled by intensive harvesting but the rate is still only 0.4% per rotation because of the very large pool of potassium in the soil at this location. At Oak Ridge, the natural loss is increased by a smaller amount but this is a larger fraction of the potassium present in the forest. Nonetheless, the loss with intensive harvesting is only 2.4% per rotation. At Clemson, the natural accumulation of potassium is cut in half by commercial harvesting and reduced to a small deficit by residue removal. At the Florida location, the small loss of potassium is turned into a relatively large loss. Residue removal has a relatively small incremental impact compared to commercial harvesting.

Relatively little data has been collected on magnesium. At the present time, all that can be said is that at the Florida location there is apparently a loss during both types of harvest.

Calcium is the nutrient that appears to suffer the greatest impact. At Coweeta, the fractional loss per rotation is increased from 10 to 16 and 27% by commercial and intensive harvesting respectively. At Oak Ridge the figures are even larger. A natural decrease of 40% per rotation is increased to 56 and 80%. At Clemson, a significant natural accumulation of calcium is turned into a small loss by commercial harvesting and a large loss by intensive harvesting. At the Florida location, a small depletion becomes a large deficit under both types of harvest.

Calcium also appeared to be rapidly depleted in whole-tree harvesting on a northern aspen-hardwood site described in a previous study (Boyle, et al., 1973). These figures present some puzzling implications. It is difficult to see how even the natural forest can sustain itself at Oak Ridge with the estimated loss of 40% of the calcium over a 30 year period. It is tempting to suspect some kind of error in the measurement. For example, collectors may not accurately measure net atmospheric inputs as suggested by Stone (1979). Alternatively, the trees may be able to tap calcium stores deep within the soil (Pritchett, 1979, p. 103; Stone, 1979). Another possibility is that these forests are indeed losing calcium, but the previous forests at these locations did not. A further complication in interpreting the significance of these results is that calcium has never been demonstrated to limit crop growth (Thompson & Troeh, 1973, p. 313), and few examples of deficiencies in forests have been reported (Pritchett, 1979, pp. 103 & 200; Ballard, 1979).

Analysis of the above data should be tempered with several considerations. The fractional change in nutrients was calculated using the total amount present. This is the most optimistic assumption, since most of the nutrients (aside from nitrogen) are present in the minerals of the soil and not immediately available for use by trees. They become available by geochemical weathering (Armson, 1977) and, as yet, obscure biological processes (Boyle and Voigt, 1973). But little is known about the rate at which these processes occur (Clayton, 1979). For a ballpark estimate, the best available measurements are from the study of Cleaves, et al., (1970) for a water shed in the Piedmont of Maryland. In this location, the rate of release by weathering was 2.3 and 1.3 kg/ha/yr for potassium and calcium respectively. These rates would be insufficient to cover the deficits at any but the Florida location.

Another point that needs to be taken into account in considering these estimates is that the nutrient fluxes have been measured in relatively mature forests and they might be considerably different in other phases of the rotation. However, in the absence of better data, these mature forest estimates can be reasonably used because nutrient cycling is rapidly restored after harvest (West and Mann, 1982, p. 109) which implies that the phase of the rotation does not seriously change the rate of accumulation.

Forest nutrient dynamics do not appear to be significantly different in the unharvested, commercially harvested, or whole-tree harvested acreages (Cole and Gessel, 1965). Indeed, preliminary results at Coweeta indicate that post-harvesting nutrient loss with residue removal was not significantly different from unharvested forest, although the conventionally harvested forest had higher losses the first year (West & Mann, 1982, p. 106). This can be explained by faster revegetation when logging residue is removed.

Another weakness is that the nutrient fluxes were measured over a short time interval, at least in comparison to climatic and geological events. Thus, the results could be misleading because of an unusual climatic or geological situation at the time of the measurements. For instance, the increased atmospheric dust from geologic events could increase the nutrient inputs-or a drought could reduce the output. In spite of these qualifications, there are no better estimates available at the present time.

3.1.1.2 Environmental Assessment

Data exist for only a few forest types in research to date, as discussed in the previous section. The first step, to quantifying environmental impacts therefore, is to determine which forest-type and harvest-method most closely fits the type of biomass estimated for each source for each state. The choice in some cases is clear-cut. Other decisions are not obvious, such as whether a particular state's softwood forests are more characterized by a loblolly pine forest profile or a slash pine forest profile. The forest profile utilized from the tables given earlier for each state and biomass source are given on Table 3.5. Milling residues are not included on this table because they are already being removed from the forest ecosystem with very little return. To use these residues for energy, therefore, has no measurable impact on the forest environment.

The nutrients identified as being areas of concern include nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), and magnesium (Mg). The impact of removing biomass on these nutrients is an exceedingly complex issue about which little data exist. West and Mann (1982) provide the only quantitative estimates of rates of removal and replenishment of these nutrients though, as noted previously, this work has not yet been completed and is not of sufficient scope to address the complete mechanism. For example, there is incomplete measurement and explanation of the mechanism by which mineral deposits enter the forest ecosystem. The application of nutrient depletion rates thus derived, therefore, must be done with the greatest caution with the recognition that such application can only be considered as a first approximation.

Table 3.5

Forest Profiles Applicable For Each State

	Collected Residue				Increases to Growth
	Hardwood	Softwood	Thinnings*	Conversion*	(All Scenarios)
AL	Coweeta	Florida	Florida	Florida	Coweeta
FLA	Coweeta	Florida	Florida	Florida	Coweeta
GA	Coweeta	Clemson	Clemson	Clemson	Coweeta
KY	Oak Ridge	Clemson	Clemson	Clemson	Oak Ridge
MISS	Coweeta	Florida	Florida	Florida	Coweeta
NC	Oak Ridge	Clemson	Clemson	Clemson	Oak Ridge
SC	Oak Ridge	Clemson	Clemson	Clemson	Oak Ridge
TN	Oak Ridge	Clemson	Clemson	Clemson	Oak Ridge

*Area impacted was provided by Forestry Service data which also implied a harvesting intensity.

Each source of forestry biomass can imply different nutrient depletion rates depending on the proportion of stems and tops to logs as well as the intensity of removal. For collectable residues, the intensity of removal (in megagrams per hectare) is assumed to be the same as that reported in West and Mann (1982) for "residues." Increases to growth are assumed to be collected with intensity equal to that of "harvesting with residues." In all likelihood, increases to growth, particularly if it is derived from short rotation woody crops, will probably be accomplished with a higher intensity than reported by West and Mann and, as well, will probably consist of a higher proportion of the biomass which contains the greater nutrient concentration. As such, the nutrient depletion rates for the increases to growth for energy will probably be higher. The extent of this bias cannot, however, be quantified with existing data. Thinnings and conversions are assumed to occur at intensities implied by the Forestry Service data even though these data appear to be lower than what would be expected. The nutrient depletion rates reported by West and Mann (1982) are applied proportionally according to those removal intensities.

The total quantities of nutrients depleted through biomass harvesting and collection could be estimated from the information presented but would have very little value in predicting the environmental impact. A more useful exercise is to develop a worse-case nutrient depletion scenario based on the impacts on nutrient balance of higher intensity harvesting and collection practices. Such a scenario would be consistent with the practices of short rotation woody crops with the biomass having nutrient concentrations consistent with the residue component presented by West and Mann (1982). The data available to construct the scenario are crude but can still provide insight into those areas which may be the greatest problem.

The candidate species for short rotation woody crops more closely resembles the profile for hardwoods as far as nutrient uptake and removal are concerned. Therefore, the two hardwood profiles applicable to the southeastern region presented previously were used to simulate the scenario are provided on Tables 3.6 and 3.7. Because the crop rotation period is different between reported harvesting profiles, and the simulated short rotation woody crop scenarios, it is more appropriate to compare average annual changes to the nutrient balance. For the Coweeta Mixed Hardwood Forest, the higher intensity harvesting caused all nutrients to be deficits including nitrogen, which had previously been positive even with residue collection. For the nutrients which had been negative before, the deficit was predictably higher. The degree of increase to the annual deficit was by factors of about 4 for K to 14 for P. The Oak Ridge Mixed Hardwood forest shows an even more dramatic increase to the nutrient balance deficits. The largest absolute change was an increase in the deficit for Ca of 139.4 Kg/ha per year. The largest relative change was in nitrogen which went from -.6 Kg/ha per year to -40.7 Kg/ha per year -- a 68 fold increase to the deficit.

The inescapable conclusion of these scenarios is that short rotation woody crops cannot be harvested without either depleting the nutrients in the ecosystem and reducing the productivity of the land thereof, or requiring application of nutrients in a manner not dissimilar to that found in agriculture. Forest nutrient dynamics are greatly different from those in agriculture, however. Those differences are not well understood at the present time so that the ability to maintain forest productivity through external nutrient application is not certain.

Table 3.6

Coweeta Mixed Hardwood Forest Profile
Nutrient and Biomass Input/Output
Short Rotation Woody Crops
One Rotation Scenario
(crop rotation = 7 years)

		Biomass (Mg/ha)	Nutrients (kg/ha) N	P	K	Ca
I.	Total Pool		7,307	N.A.	124,317	3,288
II.	Harvest	178	277	41	216	544
III.	Input/year		21	.2	1.6	4.9
IV.	Output/year		13	.1	5.6	9.8
V.	Net change/rotation*					
	A. No harvest		56	.7	-2.8	-34.3
	B. Harvest		-221	-40.3	-218.8	-578.3
VI.	%Change/rotation*					
	A. No harvest		.8%	-	-.02%	-1.0%
	B. Harvest		-3.0%	-	-.2%	-17.6%
VII.	Average Annual/Net Change*					
	A. No harvest		8	.1	-4.0	-4.9
	B. Harvest		-31.6	-5.8	-31.3	-82.6
VIII.	Average Annual % Change					
	A. No harvest		-.1%	-	0.00%	-.1%
	B. Harvest		-.4%	-	-.03%	2.5%

+Negative numbers indicated deficits which would have to be made up through external application to maintain productivity.

Table 3.7

Oak Ridge Mixed Harwood Forest
Nutrient and Biomass Input/Output
Short Rotation Woody Crop
One Rotation Scenario
(crop rotation = 7 years)

		Biomass (Mg/ha)	Nutrients (kg/ha) N	P	K	Ca
I.	Total Pool		3,652	1,370	21,999	2,680
II.	Harvest	165	312	22	125	1,084
III.	Input/year		6.9	.6	4.2	4.6
IV.	Output/year		3	.5	10	20
V.	Net Change/Rotation*					
	A. No harvest		27.3	.7	-40.6	-107.8
	B. Harvest		-284.7	-21.3	-165.6	-1191.8
VI.	% Change/Rotation*					
	A. No harvest		+.7%	+.1%	-.2%	-4.0%
	B. Harvest		-7.8%	-1.6%	-.8%	-44.5%
VII.	Average Annual Net Change					
	A. No harvest		3.9	.1	-5.8	-15.4
	B. Harvest		-40.7	-3.0	-23.7	-170.3
VIII.	Average Annual % Change					
	A. No harvest		-.1%	0.01%	0.01%	-.6%
	B. Harvest		-1.1%	-.2%	-.1%	-6.4%

*Negative numbers indicate deficits which would have to be made up through external application to maintain productivity.

Another measure of the potential environmental impact would be the area likely to be affected for each biomass source under each energy price scenario. The total areas impacted are estimated on Table 3.8 for low, mid and high energy price scenarios. For comparison purposes, the total commercial forest area is also provided and percentage calculated for the mid price scenario. A large variation is seen in those percentages from 28.8% (Tennessee) to .02% (Kentucky). The reason for the large variation is revealed by examining the areas by source presented on Table 3.9 where it can be seen that the states of Alabama, Mississippi, and Tennessee show disproportionately large areas for Thinnings. These large estimates are probably due to underestimates of the thinning intensity implied by the Forest Service data, but without other estimates this cannot be resolved. Fortunately, the large variance in thinnings are is not vitally significant, as it represents a very low intensity of environmental impact. Table 3.8 also provides percentages of total commercial forest excluding thinnings area and the variation between states is greatly reduced.

Table 3.8

Projected Area Impacted By Biomass Utilization For Energy By State and Scenario Year 2000 (10^3 Hectares)

	Low	Mid	High	Total* Forest Land	% of Total (Mid)	% of Total (Mid) (Excluding (Thinning)
AL	12,688	12,698	12,717	50,982	24.9	3.4
FL	1,189	1,193	1,203	35,728	3.3	2.9
GA	2,589	2,595	2,605	56,991	4.6	3.8
KY	48	57	77	28,624	.02	.02
MISS	10,000	10,008	10,026	38,822	25.8	3.6
NC	2,301	2,304	2,307	46,054	5.0	4.3
SC	1,343	1,343	1,349	28,829	4.7	4.0
TN	9,020	9,028	9,043	31,379	28.8	4.0

*Source: U.S. Forest Service, Forest Statistics, 1977.

Table 3.9

Year 2000 Projected Area Impacted by Source of Forestry Biomass (10^3 Hectares)

	Collected Residue		Thinnings	Conversion[1]	Increases to Growth (hardwood)		
	Hardwood	Softwood	(softwood)	(hardwood)	Low	Mid	High
AL	76	92	10,947	1,561	12	22	41
FLA	47	98	173	858	13	17	27
GA	57	58	415	2,058	1	7	17
KY	39	.4	-	-	9	18	38
MISS	85	52	8,624	1,230	9	17	35
NC**	144	112	343	1,702	0	3	6
SC**	90	69	198	986	0	0	6
TN	77	62	7,764	1,108	9	17	32

**Collected residue, thinnings and conversion areas are likely to be slightly less under the lower/mid price scenario.

3.1.2 Depletion of Soil Humus

Humus is the organic part of soil that is slow to decompose. In agriculture it is considered important in maintaining soil productivity by providing water absorbing capacity as well as nutrients (Thompson & Troeh, 1973, p. 102).

In forestry, less weight is placed on the humus content of soils because of the great differences in the soil mechanisms between agricultural and silvicultural environments. First, because of stratification, forest soils are more complicated than the artifically mixed soils of traditional agriculture. As a consequence, simply measuring average humus content is neither as easy nor as meaningful in forest soils as agricultural soils. A second aspect is that water availability is less likely to be limiting for trees with deep roots than for relatively shallowly rooted crops. Although water availability is often the most important factor limiting how growth even in forests (Armson, 1977, p. 257), it is not clear how humus accumulation/depletion affects water availability in the forest environment. Despite the lack of empirical analyses of the mechanism(s) by which humus affects forest dynamics, it can be said that impacts exist. For example, humus accumulation assists in decomposition by holding moisture thereby returning a higher percentage of biomass to the soil rather than losing it in run-off to surface waters. Humus also retards erosion and may affect ground water aquifer recharge rates. For these reasons, it is important to consider whether whole-tree harvesting is likely to lead to a reduction of the humus content of soils.

Humus is primarily formed by the decomposition of litter. Roots also contribute organic material to soil but if their contribution were major, one would not expect to find forest soils as highly stratified as they are. Humus is decomposed primarily by microorganisms. The decomposition is relatively easily measured by monitoring the production of CO_2 (respiration) of soil. In a mixed hardwood site at Oak Ridge, Tennessee, the carbon content of the upper 45cm. of soil was 3300 g/m^2. The carbon oxidized to CO_2 during soil respiration was 30, 36, and 44 g/m^{-2} yr. in sites that where uncut, commercially harvested, and harvested with residue removal respectively (West & Mann, 1982, p. 89). These numbers suggest that, if the input of organic material to soil is terminated, the humus would be substantially reduced in a very few rotations. Harvesting the trees appears to speed up the rate of decomposition. Thus, the reduction of humus will be increased even beyond what is expected by reducing the input of organic material.

A crucial question is to what extent does residue removal during harvest decrease the organic material added to soil during the harvest rotation. Pritchett (1979, p. 60) observes that the rate of litterfall for a variety of forest species and locations is usually close to 3 tons per hectare. This is consistent with that reported in other works for pine forests in Florida (Heyward & Bennett, 1936, p. 17). If this figure is combined with the commercial and whole-tree harvest measurements of West and Mann (1982, p. 3), an estimate of the humus accumulation can be made. These data are provided on Table 3.10. The difference in quantities harvested between these two methods produces an estimate of the incremental residue that is removed during intensive harvesting. The rotation length times the rate of litterfall yields the total litterfall per rotation. The ratio of residue to the sum of residue and litterfall produces an estimate of the fraction of the organic input to the surface in commercial harvesting that is removed in intensive harvesting. For all four sites, this estimate is close to 30% (range 27-36%). This is a substantial decrease.

3.1.3. Erosion and Sedimentation of Streams

The Biomass Energy Systems Program Environmental Assessment (1973) identified erosion and stream sedimentation as major environmental problems

Table 3.10

Logging Residue Compared to Litterfall

	Site			
	Coweeta	Oak Ridge	Clemson	Florida
Harvest (Mg/ha)				
With Residue[1]	178	165	132	142
Commercial[1]	58	64	79	108
Residue (difference)	120	101	53	34
Rotation (yrs)[2]	70	70	40	30
Litterfall/yr (Mg/ha)[3]	3	3	3	3
Litterfall/rotation (Mg/ha)	210	210	120	90
Residue (Litterfall + Residue)	36%	34%	31%	27%

[1]From West and Mann (1982, p. 3).

[2]From West and Mann (1982, p. 11).

[3]Average for variety of species and locations (Pritchett, 1979, p. 60).

associated with tree harvesting in the U.S. (Tufts University, 1982, pp. 15 & 18). These problems are potentially even more severe in the Southeast (Hornbeck & Usic, 1979) where the rainfall erosion potential is very high (Thompson & Troeh, 1973, p. 458) due to spring thunder storms and hurricanes. Erosion results when rainfall exceeds the infiltration capacity of the soil and the excess water runs off over the surface. It is generally considered that for a forest floor with a significant accumulation of organic material, the infiltration rate exceeds the maximum rainfall rate in nearly all cases (Armson, 1977, p. 243). Estimates of erosion rates on forested watersheds of the Southeast are in the vicinity of 0.05 tons/acre/year. Almost all measurements are below the regional average of 0.2 - 0.3 ton/acre/year for all land areas (Patric, 1976). Thus, erosion becomes a problem only when the surface litter is removed by skidding logs or building roads. Indeed, it is commonly observed in practice that visable erosion on clear cuts occurs mostly on roads (EPA, 1973, p. 26; Patric, 1976; Corbett et al., 1978).

However, proper logging procedures have been observed to practically eliminate increased erosion (Aubertin and Patric, 1974; Patric, 1976; Corbett et al., 1978). The major steps are appropriate design and construction of roads and maintenance of a protective strip of intact forest along streams. Such a strip helps maintain low water temperatues as well as reduce erosion and nutrient loss (Hornbeck & Ursic, 1979).

In the ongoing study of the effects of whole-tree harvesting, erosion did not seem to be increased by harvesting. At the Oak Ridge location, harvesting had no effect on surface run off and there was little visable evidence of erosion (West and Mann, 1982, p. 87). At Clemson during the 10 months after harvest, stream turbidity was twice as high on the whole-tree harvested water shed as the control, with the conventionally harvested watershed intermediate (West and Mann, 1978, p. 10). However, in terms of amount of sediment per land area over the 10 month period, the conventionally harvested watershed was five times the control with the whole-tree harvested watershed intermediate. In any case, rapid revegetation quickly reduced erosion on the harvested sites. The direct effect of residue removal would be expected to be increased erosion. However, since residue removal speeds revegetation (West and Mann, 1982, pp. 92, 109), the long-term effect may, in fact, be to reduce erosion. Thus, the net effect of residue removal is complicated but probably does not have a large impact on erosion or water quality as long as humus is not being depleted and soil productivity is adequate.

3.1.4. Assessment of Environmental Impact - Humus Depletion, Erosion and Sedimentation

The sources of supply of forestry biomass affect erosion, soil humus depletion and stream sedimentation to varying degrees and each sources' impact is contingent upon several factors. Residue collection for example, can actually decrease total erosion. through a quicker revegetation of harvested lands if adequate nutrient levels are maintained. However, as shown on Table 3.10, the practice of harvesting with residue reduces the litterfall accumulation rate by about 30%. If a short rotation scenario is imposed on this profile then the reduction to total litterfall per rotation approaches 85%. It is not possible to state decisively that this would cause a net deficit in the humus accumulation balance and, in all likelihood, this would depend on a large number of other variables such as rainfall intensity, soil type, and degree of slope. If there is a deficit in the humus accumulation balance, however, then it can be said that eventually bare soil would become exposed and subject to severe erosion and a concurrent drop in productivity.

Data for existing erosion rates are available in only very general terms. Table 3.11 presents the latest and most detailed disaggregation for forest land erosion rates. Biomass sources would come predominantly from forest lands which are nonfederal, nongrazed, and nonwetlands so this is the category on which this analysis will focus. While it is not possible to forecast increases to erosion amounts from the available data, it is possible to construct illustrative scenarios which can give insight into the magnitude of the potential problems. For example, if it is assumed that biomass harvesting practices which have the greatest potential for increasing erosion rates, i.e., residue collection, forest conversion and increases to growth through SRWC cause land previously eroding at a rate of less than 2 tons per acre per year (or .73 Mg per hectare) to erode at 5 tons per acre per year (or 1.84 Mg per hectare). The resulting marginal increase to soil lost through erosion can then be calculated for the three energy price scenarios. The results of this calculation are presented on Table 3.12. The total soil lost to the hypothesized erosion increases are not large for any of the states. Total existing soil loss rates by erosion are not available for comparison

Table 3.11

Forest Land-Erosion-Sheet and Rill

			Nonfederal						
				Grazed			Not Grazed		
				2T/a/yr			2T/a/yr		
State	Total	Federal	Total	Wetlands	NonWet	2T/a/yr	Wetlands	NonWet	2T/a/yr
ALABAMA	50,982	2,076	48,906	1,053	1,819	1,132	9,261	35,642	
FLORIDA	35,728	5,730	29,998		7,057	284		22,657	
GEORGIA	56,991	3,702	53,290		10	20	21,520	30,255	1,478
KENTUCKY	28,624	2,313	26,311	57	966	2,498	781	15,029	6,981
MISSISSIPPI	38,822	3,210	35,612	1,250	3,536	976	10,3434	16,783	2,733
N. CAROLINA	46,054	4,510	41,545	170	1,416	230	17,183	22,489	57
S.CAROLINA	28,829	2,216	26,613	235	927	37	12,019	13,094	301
TENNESSEE	31,379	2,622	28,757	141	2,402	1,404	2,078	17,695	5,038

Source: Appraisal Part 1: Soil, Water, and Related Resources in the U.S., Status Conditions and Trends, U.S. Forestry Service, 1980 pp. 87, 94, 96, 98, 171-173, 175, 177, 178.

Table 3.12

Marginal Estimated Increase to Soil Eroded
(10^3 Mg)

	Low	Mid	High
ALABAMA	4.74	4.77	4.82
FLORIDA	2.77	2.78	2.80
GEORGIA	5.92	5.93	5.96
KENTUCKY	.13	.16	.21
MISSISSIPPI	3.74	3.77	3.82
NORTH CAROLINA	5.33	5.34	5.35
SOUTH CAROLINA	3.12	3.12	3.13
TENNESSEE	3.42	3.44	3.48

purposes but it can be said that by far the largest soil losses occur in agricultural areas rather than forest areas and this is likely to continue to be the case.

Another aspect of this potential problem could be the accumulated effects of converting low erosion-prone lands to higher erosion prone lands. To illustrate this, Table 3.13 provides the percentages of area affected by residue collection, conversion and increases to growth to total nongrazed, nonwetland forest. There is not a great

Table 3.13

Percentage of High Erosion Potential Land
to Total Non-Grazed, Non-Wetland Forest
(10^3 Hectare)

	Low		Mid		High		Total
	Area	%	Area	%	Area	%	Forest
AL	1,741	4.88	1,751	4.91	1,770	4.97	35,642
FL	1,016	4.48	1,020	4.50	1,030	4.55	22,657
GA	2,174	7.19	2,180	7.21	2,190	7.24	30,255
KY	48	0.32	57	0.38	77	0.51	15,029
MISS	1,376	8.20	1,384	8.25	1,402	8.35	16,783
NC	1,958	8.71	1,961	8.72	1,964	8.73	22,489
SC	1,145	8.74	1,145	8.74	1,151	8.79	13,094
TN	1,256	7.10	1,264	7.14	1,279	7.23	17,695

variance across scenarios for each individual state. The variation across states is larger though still not by a wide margin with the exception of Kentucky. They do represent significant percentages, however, approaching 9% in some cases.

Even though the erosion, stream sedimentation and decreases to humus may not be significant on a state-wide basis, particular areas could still be greatly affected.

It should be noted that the largest source of erosion in the forest environment is currently from disturbances occuring as a result of improper logging practices. If appropriate procedures are employed, i.e., adequate design and maintenance of roads and buffer areas, then increases to erosion through higher intensity collection procedures can be greatly ameliorated. Additional measures are likely to be necessary for forestry practices employing both higher intensity growth and harvesting regimes.

3.2. Agriculture

3.2.1. Erosion

Removing crop residues for energy production is likely to have negative effects on soil productivity. One effect will be to increase soil erosion. Crop residues play a major role in reducing erosion of agricultural lands. In the Southeast, a great potential for erosion exists, as previously mentioned, because of episodes of intense rainfall. This has lead to the erosion of cropland which exceeds established tolerance levels in many areas.

Erosion occurs when soil particles are dislodged and carried off in running water. The impact of rain drops on soil helps dislodge particles and causes a compacted surface layer to form which increases runoff (SER I, 1979). The velocity of the runoff determines how large a particle can be transported and, if sufficiently great, can itself dislodge particles. Crop residues directly protect against erosion by both reducing raindrop impact on soil and by decreasing runoff velocity (Larson, 1979). The decreased velocity, in addition to reducing the ability of the water to carry larger particles, allows more time for infiltration into the soil and thus reduces runoff volume (Adams, 1966).

In the Southeast, sheet and rill erosion from water on agricultural lands in 1975 ranged from less than 5 tons of soil per acre per year in south Florida to more than 25 tons per acre per year in parts of Mississippi, Alabama, and Tennessee. More than half of the Southeast study area lost between 15 and 25 tons per acre per year. Estimates of tolerable soil loss, i.e., the maximum amount that can be lost without affecting long-term productivity, average about 10-11 tons per acre per year (Larson, 1979). Even without the removal of erosion deterring crop residues, soil loss from much cropland already exceeds tolerable limits.

Campbell, et al., (1979) used the universal soil loss equation, which takes into account rainfall, soil erodibility, slope length and gradient, crop management, and erosion control practices (Gupta et al., 1979), to estimate water erosion losses in the major land resource areas (MLRA's) of six southern states; Alabama, Georgia, Mississippi, North Carolina, South Carolina, and Virginia. Weighted averages of estimated soil loss were then compared with tolerable soil loss limits. Soil loss in 13 of 14 MLRA's exceeded tolerance levels, indicating that much of the land could not afford any residue removal under present cropping systems.

Campbell, et al., (1979) also predicted minimum requirements of crop residues necessay to control erosion using various cropping systems and tillage methods. MLRA 153, the Atlantic Coastal Flatwoods, appears to be the largest source of available residues not needed to control erosion. Only 25% of the crop residues produced in the fraction of the MLRA in Georgia are necessary for erosion control, leaving 75% available for other uses. Overall, 40% (about 3 million metric tons) of the residue produced in Georgia, South Carolina, and North Carolina could be removed if collected evenly throughout the region and used for energy production. Less than 10% of residues produced in Alabama and Mississippi are available. The remainder must be used to protect against a high potential rate of erosion in those areas.

While these predictions of available residues are quite useful, it must be realized that only the erosion control function of crop residues was considered. In the Southeast, this may be the most important function of crop residues and the one most difficult to replace by artificial means. Chemical fertilizers could replace lost nutrients to a certain extent and sewage sludge could help to maintain the organic component of soils. In fact, it has been reported that nutrient loss through soil erosion is greater than loss through actual removal in residues and that if enough residues are left to protect against erosion, the requirements for organic matter in the soil will also be substantially met (SERI, 1979).

Erosion of soil is site specific and can vary from year to year. Averages cannot be applied to large areas where some sites are much more prone to erosion than others. The success of a residue removal program will depend greatly on the farmers' good judgement. Contour cropping, terracing, or crop rotations may be necessary (Robinson, 1980). Conservation tillage will be required and limits of residue removal must be adhered to strictly (Tufts University, 1982). It is possible that if residue prices rise significantly, individual farmers may have difficulty balancing immediate additional income with long-term productivity of cropland.

3.2.2. Depletion of Soil Nutrients

Air and water provide the carbon, hydrogen, and oxygen which comprise the bulk of plant structures. There are also fourteen other elements found to be essential to plant growth. A few of these are needed in relatively large amounts such as nitrogen, phosphorus, potassium, calcium, sulfur, and magnesium. These plant nutrients are removed from the minerals and organic matter in the soil and then returned to this pool after decomposition (Thompson & Troeh, 1973, p. 13). Agriculture interrupts this nutrient cycle by removing nutrients that are present in the harvested crop. A summary of the nutrient content in residues as compared to normally harvested biomass is contained on Table 3.14. Often future productivity is decreased because certain nutrients are not available in large enough amounts; therefore, fertilizer is applied to the land to replenish the nutrient pool.

Table 3.14

% of N, P, and K in Residues Compared
to those in Residues Plus Grain

	N	P	K
Corn	43	41	78
Soghum	57	45	86
Cotton	47	31	70
Soybeans	38	36	48

From Holt (1979).

When crop residues are removed, there is a greater nutrient deficit produced which must be compensated for by additional fertilizer applications. Any additional erosion of cropland caused by residue removal intensifies the organic matter loss. It is well known that erosion selectively removes the fine top soil particles which are relatively high in organic matter and nutrients (Slater and Carleton, 1938; Lamb, 1950; Barrows and Kilmer, 1963). Barrows and Kilmer (1963) showed that the ratio of organic matter in eroded material to that in remaining soil was 2 to 1. This was associated with a great amount of N and P lost because the forms of these nutrients available to plants are concentrated in the upper layer of soil with the organics. Almost all available nitrogen is found in the organic component of the soil (Thompson & Troeh, 1973, p. 6; Barrows & Kilmer, 1963). Potassium is found in large amounts in soil but only a very small percentage is in a form available to plants. The ratio of potassium concentration in runoff to the concentration of available potassium in the soil has been measured at about 19 (Barrows and Kilmre, 1963). Decomposing organic material is also an important source of sulfur (Thompson & Troeh, 1973, p. 6).

It is apparent that residue removal and subsequent erosion decrease nutrient levels and require that fertilizer be added to replace them. Some researchers have estimated the actual amounts of nutrients lost. Holt (1979) showed that residues are an important source of plant nutrients.

Table 3.15 compares the total amounts of nutrients present in residues in certain states to the amounts of commercial fertilizers used by those states. This gives an indication of the potential increase in fertilizer use.

Table 3.15

Comparison of Residue vs. Commercial Fertilizer Application Rates

	Nutrients (1,000 mt)			Element in residue as % of commercial fertilizer applied (potential % increase in fertilizer)		
State	N	P	K	N	P	K
Alabama	52	6	37	34	14	43
Georgia	65	8	55	25	14	31
Mississippi	106	12	66	58	37	118
N. Carolina	74	10	69	37	16	45
S. Carolina	44	5	32	48	18	40

Nutrients lost in residue removal alone will require a subtantial increase in fertilizer use. Larson (1979) estimated the nutrients lost in soybean residue plus those lost by erosion in the Southeast. Values ranged between 62 and 83 kg. per hectare for N and between 19 and 31 kg. per hectare for P. This is probably a useful average of nutrient losses in all cropping systems found in the Southeast since soybean residues have relatively lower nutrient concentrations and lower amounts of residue per hectare than other crops in the Southeast, but the erosion losses are greater from continuous soybeans (Campbell et al., 1979). All of these nutrient losses must be replaced by mineral fertilizer. This is an additional cost to farmers and the potential for fertilizer run off into streams is increased.

The amount of fertilizer which must be added to replace lost nutrients may be underestimated. The N in mineral fertilizers is different from that returned to the soil through decomposing residues in that the mineral fertilizers are composed of generally more simple compounds and are also more easily leached from the soil. Also, crop residues help to "tie up" N and prevent its removal by leaching (Tufts University, 1982). There is also good evidence that nutrients added via fertilization are not used efficiently by plants when the organic matter content of the soil is low (Lamb et al., 1950).

3.2.3. Degradation of Soil Structure

Without residues there is very little return of organic matter to the soil. In addition to providing nutrients, organic matter forms the humus fraction of soil, which is important for binding mineral particles into soil aggregates that give soil an open structure allowing good aeration and water infiltration (Thompson & Troeh, 1973, p. 6).

Lamb, et al., (1950) did some very informative experiments on productivity of eroded plots (and other plots with low organic matter content) and compared this to productivity of noneroded, high organic matter plots. Adequate fertilizer was added to all study sites so that none could be considered nutrient deficient. His results showed that soil with low organic content and degree of aggregation (which depends on organic content) gave significantly lower yields than the high organic matter plots. The conclusion was that plant nutrients and water were used inefficiently where the soil did not have a high concentration of organics.

Decomposing organic matter releases substances (paricularly organic acids) that break down mineral particles making nutrients more available for plant uptake (Thompson & Troeh, 1973, p. 6). Altered soil structure causing low aeration and restricted water movement is probably another reason for this inefficiency in nutrient use (Lamb et al., 1950).

Crop residues affect soil structure and, as a result, productivity in several ways that are difficult to quantify. Lindstrom, et al., (1979) state that crop residues are important to both chemical and physical soil properties because of added organic matter and that they have an impact on long-term productivity as a result. Thompson and Troeh (1973, p. 64) maintain that large amounts of crop residue incorporated into the soil after harvest provide a high organic content and thus increase both aeration and fertility.

Residues protect the soil surface from rain impact which can cause surface sealing when small particles fill pore spaces (Adams, 1966). This can greatly inhibit water infiltration and aeration (which requires large pores in soil). Both large and small pores are necessary to hold air and water, respectively, in the soil where plant roots can access them. These pores are formed by water-stable aggregates of soil particles. These soil aggregates are held together primarily by gummy secretions from bacteria and other micro-organisms which feed on decaying plant parts. Leachates from weathering and decaying plants also bind soil particles into aggregates (Unger & McCalla, 1980). Therefore, removing crop residues could greatly decrease soil aggregation, and thereby, the necessary air and water-holding capacity.

Decreased water infiltration is a known result of residue removal. Onstad and Otterby (1979) found that increases in soil water storage as a result of leaving residues on the surface were greatest in the Southeastern United States. Up to 40mm. of extra water can be retained on some soils. Residue removal would, therefore, have an especially large effect on water storage in the Southeast and could decrease productivity where water is limiting as well as decrease water table recharge rates.

An equally important result of decreased water infiltration is the other side of the coin, i.e., increased runoff. Studies have noted that runoff is reduced when crop residues are left on the surface (Onstad & Otterby, 1979; Larson, 1979). This reduction appears to average about one-third of total runoff, but the amount is, of course, highly variable (Onstad & Otterby, 1979). Run off will increase when crop residues are removed and this could cause stream pollution problems due to sediment, nutrients, and chemical fertilizers, and pest controls.

3.2.4. Assessment of Agriculture Environmental Impacts

The utilization of agricultural biomass for energy can have very great negative environmental impacts which can potentially exceed those of forestry derived biomass. The corresponding potential for agricultural biomass utilization levels, however, is much lower than forestry due to several factors. First, agricultural biomass tends to be extremely seasonal in its supply. Because long-term storage of such materials would require protection from rain it is seldom economical considering its bulky nature. This would imply that the predominant usage of such materials would necessarily be coincident with its collection. The activities which suggest themselves as likely candidates for this would center around the agricultural sector itself such as processing related to the harvest. This is seen to be the case, for example, in the sugar cane industry where bagasse provides the primary boiler fuel.

Another difficulty with agricultural biomass is the high relative dispersion of the materials. This is coupled with the relatively high ash and moisture content of agricultural biomass to provide a low heat energy per unit of area. Because collection costs are such a large factor in all biomass materials cost, supply is less likely to respond to higher alternative fuels costs. Furthermore, the harvesting technology would have to change to accommodate a higher biomass harvesting level. This is in direct opposition to the historical trend of harvesting technology which has been to minimize the collection of extraneous biomass due to the high transportation and handling costs associated with them as well as the recognized benefits to leaving these materials in the field.

The recognition of the existence of these factors does not, however, provide the quantitative impacts of the energy price scenarios assumed for this study. The supply cost functions for agricultural biomass would be extremely site specific as well as varying greatly over the seasons. The characteristics of the supply function do suggest, however, that little price sensititivy would exist, i.e., the supply curve is highly inelastic. This is not to say, however, that some agricultural biomass is not being used as fuels. Harvest practices for some crops, such as peanuts and rice, also collect hulls with the crop. These have historically been considered either as a feed or simply as waste. In either case, little was returned to the field. These have been used as fuels successfully but even there, usage has been fairly specialized. It is likely that the dispositional split of feed/waste/fuel of collected residues <u>would</u> be affected by alternative fuel prices but whether or not they are collected in the first place would be much less.

Another potential agriculturally-related biomass source is anaerobic digestion of animal wastes for methane production. As discussed in Chapter 1, this process is most feasible in conjunction with large feed lot operations. Potential quantities of biomass from this source are not available, but these operations are not common in the southeast. In any event, it is not likely that now dispersed animal wastes would be collected in response to higher conventional energy prices. It is possible that feedlot wastes now being dispersed as a soil conditioner/enricher could be divested to methanation to the extent that the digested sludge is not returned to the land following methanation, a loss to the agricultural ecosystem would result. However, the essential qualities of animal wastes which make it attractive to the agricultural sector are retained and, in some ways, even enhanced by the digestion process. For this reason it is likely that the application of anaerobic digestion at feedlot operations could even increase the amount of biomass returned to the agricultural sector with the attendant improvement to the agricultural ecological system.

3.3. Aquaculture

Aquatic plants are being considered as a possible source of material for the generation of energy (Tufts University, 1982). In contrast to the previously discussed sources which represent mostly simple modifications of current practices in forestry or agriculture, the use of aquatic plants would represent a relatively new technology in the United States. Thus the potential environmental impacts are much more uncertain.

Analyses performed so far indicate that the prospect for using aquatic plants solely for energy production is limited. Land with water available has many competing potential uses and the net energy gain is not promising. For instance, in one small-scale experiment more energy was expended in simply harvesting "weed" water hyacinth than was contained in the plants (Bagnall & Hentges, 1979). Thus, much more energy efficient means of harvesting and drying need to be developed before aquaculture can make a contribution to energy production.

A more promising approach is to grow water plants that have some value other than as a source of fuel so that the energy use does not bear the entire cost of production and harvest. The production of food for humans or domestic animals and special chemicals are obvious possibilities. Another use that has received a good deal of attention is waste water treatment. In this application, the aquatic plants are used to remove nutrients and perhaps toxic metals from the water. The plants could then be used as a source of energy and the clean water produced helps support the costs. Since economic application requires a warm, wet climate, this approach would be primarily restricted to Florida and the Gulf Coast.

One problem with water hyacinth waste water treament is that relatively large amounts of land are required. One hectare could treat the sewage from 200 people and produce about 100 tons/yr. of plant material. This will further limit the application of this technology, since land near population centers is scarce. The effects on water quality will be positive, since water treatment is the main objective. Odor problems are expected to be minimized by the low concentrations of organic material in the ponds. A special problem that remains to be worked out is that of mosquito control, since the ponds are ideal breeding sites. This presents a public health problem as well as a nuisance, since mosquitos can spread diseases. Another potential nuisance is escape of the water hyacinth to waterways where they can become a serious pest. The fate of infections and toxic materials in the waste water during this type of treatment also remains to be studied.

In summary, the extent of application of aquaculture technology is uncertain but will probably be very limited. The most promising use appears to have little adverse impact on the environment if properly conducted, but has the potential to produce some specialized problems such as undesirable plant propagation in natural ecosystems.

3.3. Assessment of Transportation Impacts

Biomass collected must be transported to the utilization site. Agricultural residues are, generally, uneconomical fuels if transportation is required, as previously discussed. Forestry residues, however, are generally transported though not for great distances. The two transportation modes likely to be utilized would be truck and rail. The split between the two alternative modes, however, is not clear. It is likely that biomass transportation distances would be relatively small; however, if any of their relative economic advantages were to be maintained. This suggests that trucking would be the predominant mode because virtually all biomass would be removed via trucks and to transfer to rail would require another unloading - loading cycle which could probably not be justified if costs are to be kept low. It was, therefore, assumed that trucking would be the only mode chosen though undoubtedly, some rail would occur. The negative environmental impacts of trucking are generally considered to be greater than those of rail so this analysis should be considered to be a worse-case scenario. The price data for forestry biomass previously presented was calculated with an assumption that the average trip was 25 miles. This will, therefore, assumed to hold here as well. The average wood chip truck holds approximately 22 tons (or about 20 Mg). It is, therefore, easy to estimate the total miles travelled using the quantity estimates of biomass supply. Table 3.16 displays these estimates by state as well as the estimates of the number of trips. For comparison purposes the latest truck mileage (total, excluding pick-ups and panel trucks, and total specific to forest and lumbering) is also given on Table 3.16.

Table 3.16

Trucking Increases
Projected Year 2000
by State and Energy Price Scenario

	Low		Mid		High		Total*	Forest * and
	10^3 Trips	10^6 KM	10^3 Trips	10^6 KM	10^3 Trips	10^6 KM	Truck-KM (10^6)	Lumbering 10^6
AL	1,026	41.04	1,108	44.32	1,280	51.20	2,660	367
FL	715	28.60	757	30.28	843	33.72	4,567	23
GA	719	28.76	766	30.64	861	34.44	3,682	292
KT	326	13.04	372	14.88	495	19.80	1,929	29
MS	1,011	40.44	1,086	43.44	1,244	49.76	638	77
NC	1,159	46.36	1,229	49.16	1,369	54.76	3,402	175
SC	687	27.48	724	28.96	800	32.00	1,500	126
TN	796	31.84	859	34.36	989	39.56	2,073	45

*Source: U.S. Census of Transportation 1977 (TC77-T-52)

NOTE: Both categories exclude pick-up and panel trucks.

The impact on truck miles is, of course, different for each scenario. The percentage increases to total truck miles ranges from 3.1% for the low energy price scenario to 7.6% for the high energy price scenario. The impact on forestry and lumbering truck miles, is, predictably, much larger representing increases of from 55.7% to 136.5% for the low and high scenarios respectively.

The environmental impacts of the increased trucking could be divided into three categories. The first is the emission increases; the second would be the additional wear and tear to the road network; and the third would be the increased noise to the immediate area.

The emission impact would be to degrade air quality through increases to particulates, hydrocarbons, sulfur dioxide, carbon monoxide and nitrogen oxides. Table 3.17 provides emission factors estimated by EPA for the trucking industry. Utilizing these factors, an estimate of total loading by state on air quality can be derived. These estimates are provided on Table 3.18-3.20 for the three utilization scenarios. It is very difficult to evaluate the severity of the impact, however, without knowing the precise geographical distribution of the emission. As the majority of these emissions can be expected to occur in largely rural areas, it is likely that little degradation of air quality will result. A possible exception is the increase of particulates in scenic mountain areas.

The noise pollution resulting from the trucking increase will be evident primarily in the congested areas which the trucks pass through and in the scenic/vacation areas which, though perhaps, not congested would suffer from increased noise. As with emissions, the key to the severity of impact lies in the distribution of trucking in the states.

The increases to road wear and tear have been found to be less than ten percent of total road maintenance costs. If, therefore, the road use taxes paid by the trucking firm is at least ten percent of the total cost of per unit road usage than the marginal maintenance costs will probably be recouped. It would be the responsibility of the perspective state governments to ensure the equitable distribution of road maintenance costs within a total highway administration process.

Table 3.17

Trucking Emission Factors
(Mg per Mg delivered per KM)

Particulates	.132
Hydrocarbons (HC)	.451
Sulfar Dioxide (SO_2)	.263
Carbon Monoxide (CO)	2.856
Nitrous Oxides (NO_x)	2.067

Table 3.18

Total Projected Emissions Loading
From Trucking - Low Energy Price Scenario
(Mg)

	Particulates	HC	SO_2	CO	NO_x
ALABAMA	111	379	221	2,400	1,737
FLORIDA	54	184	107	1,166	843
GEORGIA	54	186	109	1,179	853
KENTUCKY	11	38	22	242	175
MISSISSIPPI	108	368	215	2,331	1,687
NORTH CAROLINA	142	484	282	3,064	2,217
SOUTH CAROLINA	50	170	99	1,076	779
TENNESSEE	67	228	133	1,445	1,046

Table 3.19

Total Projected Emissions Loading
From Trucking - Mid Energy Price Scenario
(Mg)

	Particulates	HC	SO_2	CO	NO_x
ALABAMA	129	442	258	2,800	2,026
FLORIDA	60	206	120	1,306	945
GEORGIA	62	211	123	1,337	968
KENTUCKY	15	50	29	316	228
MISSISSIPPI	124	425	248	2,690	1,946
NORTH CAROLINA	159	544	317	3,443	2,491
SOUTH CAROLINA	55	189	110	1,195	865
TENNESSEE	78	266	155	1,682	1,217

Table 3.20

Total Projected Emissions Loading
From Trucking - High Energy Price Scenario
(Mg)

	Particulates	HC	SO_2	CO	NO_x
ALABAMA	173	590	344	3,736	2,704
FLORIDA	75	256	149	1,620	1,172
GEORGIA	69	237	138	1,503	1,088
KENTUCKY	26	88	51	559	404
MISSISSIPPI	163	557	325	3,527	2,552
NORTH CAROLINA	198	675	394	4,274	3,093
SOUTH CAROLINA	67	230	134	1,460	1,056
TENNESSEE	103	352	205	2,230	1,614

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APPENDIX A

ESTIMATION OF BIOMASS SUPPLY CURVE OBSERVATIONS

The data points for the supply curve estimation were derived from several sources. The milling residue and collectable residue quantities of both softwood and hardwood were estimated by Dunwoody, Inc. from lumbering activity data contained in two U.S. Forestry Service publications. The overall quantities expected in the year 2000 were from "An Analysis of the Timber Situation in the U.S., 1952-2030" while the disaggregation by biomass type was estimated by applying the ratios revealed in "Forest Statistics of the U.S., 1977." Quantities expected to be available from thinnings, conversions, idle cropland SRWC, and new SRWC were derived from data contained on Tables 9.13 and 9.14 of "An Analysis of the Timber Situation in the U.S. 1952-2030" by assuming a homogeneous distribution over all states in the region for which data were available. This estimation process was complicated by the fact that Alabama, Mississippi, and Tennessee were included in the South Central region while the remaining states were included in the Southeast region. Unfortunately, the data provided were slightly different for the two regions requiring further assumptions of equivalence between regions. One area where this last assumption is not born out was in the estimation of land area affected by thinnings. Large descrepancies between states in different regions arose which were not explainable by any other factors. The estimates of quantities of biomass available from each source for each state (regardless of U.S. Forestry Service Region) did appear to be remarkably consistent however, as the results from the regression reveal. The lack of consistency of thinnings area estimates does not seriously jeopardize the credibility of the environmental impact conclusions, though, due to the low marginal impact associated with removals of culls and thinnings from the forest ecosystem.

As previously discussed, each source of biomass is made available to the market place along its own supply curve. These component supply curves overlap and, taken together, provide the total market supply curve for biomass materials. While additional observation on the component supply curves were not available it was possible to develop certain assumptions about these component supply curves which were reasonable in light of the cost characteristic of each biomass source. These assumptions and the effect they had on the quantity observations used in the regressions are as follows:

Milling Residues

All of these residues were assumed to be available at a constant cost of \$.60 per MMBtu. This assumption was based on the observation that milling residues, while subject to essentially constant collection costs composed of, primarily, transportation costs while being also not quantity responsive to higher market prices for residues. The price quantity observation for each state for milling residues was therefore 100% of that estimated from forestry statistics.

Collectable Residues

In contrast to milling residues, these quantities could be expected to exhibit a wide variation in collection costs. The cost of removing the tops and large limbs during normal harvesting would be expected to be less than the collection of smaller limbs and stumps, for example. It was assumed that the average cost for these residue of \$1.40 would represent the cost at the 50th percentile of total quantities estimated as collectable. The total estimated quantity was, therefore, multiplied by .5 to provide the price-quantity observation for each state.

Thinnings

These residues were assumed to be available in a manner analogous to other collectable residues but at the higher average price of \$1.90 per MMBtu. The total estimated quantities available were, therefore, multiplied by .5 to reflect this average cost assumption.

Conversion

Forest conversion from hardwood/scrub forests to plantations are a peculiar supply source because it is not a flow-quantity. Instead it is a one-time only source for a particular area. It is true, however, that the conversions will take place over time. Because no data are available to clearly depict this time path, it was assumed that 10% of the identified conversion total quantity would be available for the forecast year of 2000.

Short Rotation Woody Crops

The SRWC component supply curve is one of the more significant potential sources of biomass. For this reason, two data points were developed. The first relates to an identified low-cost portion utilizing idle cropland. The cost for this supply was estimated to be $2.21 and the quantities potentially available were based on the Southeast U.S. Forestry Service Region disaggregation. No equivalent category existed for states in the other region. The second SRWC data point was also based on the same forestry data source but was used to approximate the total SRWC biomass potentially available. The average cost for these materials was estimated to be $7.90.

These data points were fitted to a curve using the ordinary least squares procedure of TSP. The data were entered as double logarithmic to capture the nonlinearity expected from the biomass production function.

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COST PLAN

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5. Contract Completion Date
11/82

6. Identification Number	7. Reporting Category (e.g., contract line item or work breakdown structure element)	~~8. Planned Prior Fiscal Years~~	~~9. Actual Prior Fiscal Years~~	10. Planned Current Contract Year DE	JA	FE	MR	AP	MY	JN	JL	AU	SE	OC	NO	Total	11. Planned Future Contract Years a	b	c	d	e	~~12. Planned Subsequent Fiscal Years to Completion~~	13. Total Planned Cost (Columns 8 10, 11, and 12)
				1	1	5	2	3	3	10	8	6	4.5		1								
I	Identify BES			1												1							1
II	Screen BES				1	5	2									8							8
III	Utilization Scenarios							3	1							4							4
IV	Safety Analysis									2						2							2
IV A	Production Impacts								2	4	4	2				12							12
IV B	Collection Impacts									4	4	4				12							12
	Prepare Draft Rep.												4			4							4
	Review Draft																						
	Prepare Final														1	1							1
	Travel								.5				.5			1							1
	14. Total															45							45

15. Remarks
This cost plan reflects research from December 1981, through project completion. Expenditures prior to December 1981, totalled approximately $10,000.

16. Dollars Expressed In:
Thousands

17. Cost Plan Date
4/27/82

18. Signature of Contractor's Project Manager and Date

19. Signature of Contractor's Authorized Financial Representative and Date

20. Signature of Government Technical Representative and Date